ECONOMIC GEOLOGY

VOL. XXXI MAY, 1936 No. 3

STRUCTURE AND PRIMARY MINERALIZATION OF THE ZINC MINE AT BALMAT, NEW YORK.[1]

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INTRODUCTION.

History.

AT Edwards, St. Lawrence Co., New York, a zinc mine has been operated since 1915, has reached a vertical depth of 1900 feet,

[1] Presented before Society of Economic Geologists and American Institute of Mining Engineers, joint meeting, New York, February, 1935. Published by permission of St. Joseph Lead Company.

and has a present daily output of about 300 tons of crude ore. St. Lawrence county in the past century has been noted for such other diverse mineral products as lead ore, iron ore, pyrite, talc, marble, and feldspar.

Balmat is 12 miles southwest of Edwards and 8 miles southeast of Gouverneur. The occurrence of sphalerite at Balmat was noted by Emmons [2] in 1838, but was of interest then only from its association with galena. The St. Joseph Lead Company acquired the Edwards mine and the Balmat prospect in 1926. Exploration, begun in 1927, disclosed zinc ore at Balmat in bodies more extensive than known at Edwards, although not at the site of the original showings. Development prior to production included 48,000 feet of diamond drilling of which 12 holes were more than 1,000 feet in vertical depth and two reached a depth of 2,300 feet. Production began in 1930 and now averages about 700 tons daily. This yields about 100 tons of zinc concentrates, 125 tons of pyrite concentrates, and a few tons of galena. Operation is through a shaft inclined at 40°, which extends to a vertical depth of 700 feet. Levels at 300 feet and 500 feet are fully developed, and that at 700 feet is partially completed. Economic conditions up to the present time have prevented operation of the mine at its full capacity.

Acknowledgments.

To D. H. Newland, State Geologist of New York, Prof. Heinrich Ries of Cornell University, and Prof. A. F. Buddington of Princeton, the writer is much indebted for advice and assistance. Use of the Princeton laboratories for a month, with assistance from Prof. Buddington, was particularly helpful. For critical reading of the manuscript, acknowledgment is due Professors Waldemar Lindgren and W. H. Newhouse of the Massachusetts Institute of Technology, Dr. James Gilluly, U. S. Geological Survey, and Dr. George Tunnell of the Geophysical Laboratory, Washington, D. C. Sincere appreciation is also due

[2] Emmons, Ebenezer: Geology of New York; Report on Second District. Assembly Doc. No. 200, p. 213, 1838

the officers of the St. Joseph Lead Company and its local management under Mr. R. J. Mechin for sympathetic co-operation.

Problems of the District.

The rocks of the Edwards District consist almost entirely of highly metamorphosed sedimentary units, and intrusive igneous masses, all of pre-Cambrian age, essentially a part of the Canadian shield. In most of this pre-Cambrian area the relations of the rocks are so involved that satisfactory stratigraphic and structural explanations are seldom possible. Notwithstanding a considerable amount of excellent geological work,[3] the structure and stratigraphy of its zinc mines have been but vaguely understood.

The primary genesis of the zinc ores, on the other hand, was correctly interpreted by Smyth and Newland early in the history of their exploitation. Both agreed that the ores were derived from igneous masses at depth and deposited by ascending solutions that replaced limestone. This conception has never been seriously questioned. The complex and fascinating set of secondary changes which has been superimposed on the primary ore at Balmat is apparent only to a slight degree in the other deposits of the district, and was barely touched upon by Smyth and Newland.

The problems of the region, as concerns the zinc deposits, are essentially (1) stratigraphic and structural, and (2) genetic. For stratigraphy and structure, the writer has depended mainly

[3] The following references are selected as of particular value:—Newland, D. H.: Zinc-Pyrite Deposits of the Edwards District, St. Lawrence County, N. Y. N. Y. State Defense Council, Bull. 2, 1917. Smyth, C. H. Jr.: Genesis of the Zinc Ores of the Edwards District, St. Lawrence Co., N. Y. N. Y. State Museum Bull. 201, 1917. Wade, W. R. and Wandke, Alfred: A Big Zinc Mine in New York State. Eng. & Min. Jour. Press, vol. 116, no. 3, pp. 95–99, July 21, 1923. Cushing, H. P. and Newland, D. H.: Geology of the Gouverneur Quadrangle, New York. N. Y. State Museum Bull. 259, 1925. Smyth, C. H. Jr., and Buddington, A. F.: Geology of the Lake Bonaparte Quadrangle, N. Y. N. Y. State Museum Bull. 269, 1926. Buddington, A. F.: Granite Phacoliths and their Contact Zones in the Northwest Adirondacks. N. Y. State Museum Bull. 281, pp. 51–107, 1929. Brown, John S.: Natural Gas, Salt and Gypsum in pre-Cambrian Rocks at Edwards, N. Y. Bull. Amer. Assoc. Petr. Geol., vol. 16, pp. 727–735, 1932.

on field evidence aided by microscopic data available in State reports. In studying the genesis of the ores he has supplemented the routine of mine mapping by extensive microscopic study.

GENERAL GEOLOGY.

Sedimentary Rocks.

Lower Garnet Gneiss.—The oldest formation exposed is commonly designated a garnet gneiss, and in distinction to a similar higher unit will be referred to as the *lower garnet gneiss* (Fig. 1). Microscopically it is described by Cushing and Newland [4] as composed mainly of quartz, feldspar, and biotite, with accessory garnet. The rock is of gray or brown color and contains much granitic or pegmatitic matter which is either gray or reddish. Garnet is most characteristic of the upper part of the formation, and may be lacking elsewhere.

Included with the lower garnet gneiss are two odd, irregular masses of crystalline limestone, one near each end of the oval exposure. These represent a formerly continuous limestone member which, by lateral pressure, has been obliterated on the flanks of the fold and squeezed into thickened masses along the plunging axes. Squeezed limestone areas of this nature are a common feature of the region.

The exposed thickness of the lower garnet gneiss is estimated at about 5,000 feet.

Upper Garnet Gneiss.—The highest sedimentary unit is a garnet gneiss so similar to the lower garnet gneiss that in the mapping of the Gouverneur quadrangle they were not distinguished, and in the structural interpretation of the region they were assumed to be the same. As shown in Fig. 1, the upper garnet gneiss occupies three distinct areas, isolated by intrusion, or by faulting. The three areas form a discontinuous band parallel on the northwest to the inner oval of lower garnet gneiss. The middle one of these masses, northwest of Balmat, was mapped by Cushing and Newland as gabbro amphibolite, which

[4] *Op. cit.*, pp. 29–30.

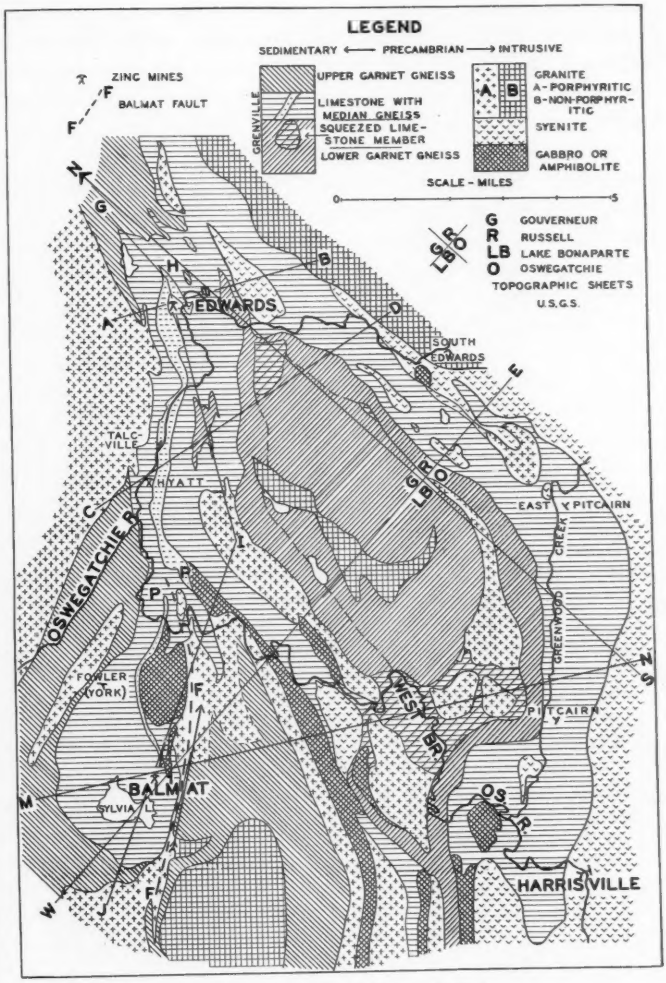

FIG. 1. Geological map of Edwards-Balmat area.

it may be in minor part but certainly not in its major outlines. This error was perpetuated in modified form in the Lake Bonaparte quadrangle [5] but later rectified by Buddington.[6] Southeast of Balmat the formation has a measurable thickness of about 5,000 feet.

Limestone.—Of prime importance is a thick limestone formation which separates the garnet gneisses (Fig. 1). In the region from Edwards to Balmat, the limestone contains much silica, either as distinctly siliceous, or quartzitic bands, or as highly silicated bands and areas containing much tremolite and diopside associated with talc and serpentine. Some of the quartzose matter is doubtless original, but the silicates and perhaps some of the quartz are due to alteration of the limestone by solutions presumably derived from granite. Nevertheless, there are considerable areas of coarsely crystalline, unsilicated limestone. From Harrisville to East Pitcairn, the limestone is almost entirely coarsely crystalline and unsilicated, except for a band immediately adjacent to the syenite. This consists of pyroxene gneiss (not shown in Fig. 1) and is interpreted by Smyth and Buddington [7] as the contact-metamorphosed equivalent of some siliceous-calcareous member. The scanty exposures from East Pitcairn to Edwards indicate a gradation from the coarsely crystalline, unsilicated type toward the silicated, serpentinous character that prevails from Edwards to Balmat.

The limestone contains a number of siliceous, generally non-calcareous members, now altered into gneiss, one of which is of especial importance as a structural reference, and will be designated the *median gneiss*. It may be characterized briefly as a granitized quartzite, and is of brown, red or rusty color. Near Edwards it contains thin lenses of interbedded limy material altered into intensely silicated, scapolitic masses of brown or green color. The median gneiss has a maximum thickness, near Edwards, of 500 or 600 feet, thinning to virtually nothing at Balmat.

A second member of some importance, not separated on the

[5] Smyth and Buddington; *Op. cit.*
[6] *Op. cit.*, N. Y. State Mus. Bull. 281.
[7] *Op. cit.*

map (Fig. 1), occurs near the top of the limestone formation in the region west of Balmat and northeast to Fowler. It consists of pyritic, siliceous, graphitic schist with associated bands of dark green pyroxene rock, the latter a contact-metamorphic alteration of limy lenses. The outcrop generally is weathered to a rusty appearance, or locally into hematite. The thickness of the member is about 200 feet. The limestone contains still other thin bands of gneiss which are exposed only locally and discontinuously, being disrupted by pressure and folding.

Including intercalated gneisses, the thickness of the limestone is estimated at about 6,000 feet.

Igneous Rocks.

Gabbro Amphibolite.—The oldest igneous rock, (Fig. 1) originally gabbro, has generally been metamorphosed into amphibolite. It is described by Cushing and Newland [8] as consisting of labradorite and hornblende, with biotite replacing hornblende in increasing amount where the rock is sheared. The chief occurrence is a large stock-like mass northeast of Balmat; it also forms a number of folded sills between Balmat and Harrisville.

Syenite.—Intrusives varying considerably in composition but all approaching the type of syenite, are classified on reasonably certain grounds as next in age. Rocks of this type occupy an extensive area southeast of Harrisville, but within the area shown in Fig. 1 constitute only a number of small plugs or irregular sills which intrude mainly the limestone.

Porphyritic Granite.—The most abundant intrusive is a red or pink porphyritic granite, generally containing flesh-colored phenocrysts about half an inch in length. Microscopically the rock is described by Smyth and Buddington [9] as composed of microcline or microperthite, oligoclase, quartz, and biotite, with minor accessories. Gneissic structure commonly is well developed, especially where the rock is interbedded with the older gneisses, and

[8] *Op. cit.*, p. 36.
[9] *Op. cit.*, p. 48.

at several places the granite shows evidence of mild granulation or shearing. Nearly all the exposures bear an intimate relation to folded structures.

Non-porphyritic Granite.—The final intrusive is also a granite, distinguishable from the porphyritic granite chiefly by its equigranular, fine-grained texture. It is described by Buddington [10] as consisting predominantly of microperthite, quartz, oligoclase, and minor accessories. A correlation of the fine-grained granite with the Laurentian of Canada is suggested by Cushing and Newland.[11] Its age relative to the porphyritic granite is not certain, but Buddington [12] suggests that the porphyritic granite is older, and the writer is inclined to agree. In any case the two probably are separated only by a brief interval, and are essentially parts of the same magma which cooled under slightly different conditions. Three areas of the non-porphyritic granite are shown in Fig. 1, two of which are closely related to pronounced folded structures.

Pegmatite.—Small pegmatite masses are abundant, particularly in the sedimentary gneisses, and to some extent in the limestone. In the gneisses they are usually pink, and in the limestone always gray. The masses in limestone form the basis of the feldspar mining in St. Lawrence County.[13] Either type of pegmatite commonly carries some black tourmaline. Both appear to be derivatives of the porphyritic granite.

Structure.

Previous Conceptions.—In previous literature the limestone belt from Edwards to Balmat has been interpreted as some sort of tightly folded syncline. In the words of one writer who graphically summarized this interpretation,[14] the structure is likened to the "horizontal longitudinal section of a dirigible air-

[10] *Op. cit.*, N. Y. State Bull. 281, p. 53.

[11] *Op. cit.*, p. 40.

[12] *Op. cit.*, p. 52.

[13] Shaub, B. M.: A Unique Feldspar Deposit near De Kalb Junction, N. Y. ECON. GEOL., vol. 25, pp. 68–89, 1929.

[14] Spurr, J. E.: Ore Injection at Edwards, N. Y. Eng. & Min. Jour. Press, vol. 117, no. 17, pp. 684–689, Apr. 26, 1924.

ship," with the qualifying statement that the section has been careened to one side and compressed until the sides are nearly parallel. It is the writer's conviction that this interpretation is erroneous, but developed naturally from a curious conjunction of features in the field evidence, combined with the piecemeal and uncompleted character of studies made by different men, in areas limited by the arbitrary boundaries of topographic quadrangles (Fig. 1). The basic error was the correlation of the two garnet gneisses, and this was due mainly to the fact that the Gouverneur quadrangle covered only a portion of the critical structure. This correlation naturally demanded that the Edwards-Balmat limestone belt constitute the axis of a fold, and certain features associated with prominent curved outcrops at Edwards and Balmat seemed to favor the synclinal interpretation.

Revised Interpretation.—The writer's conception of the structure is obvious from Figs. 1, 2, and 3. The major feature is a

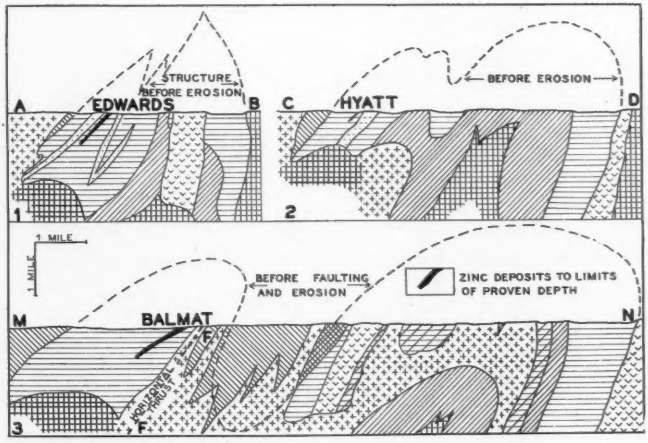

FIG. 2. Structural cross-sections, Edwards-Balmat Area.

dome slightly overturned, so that one limb dips to the northwest at about 45°, the other at about 75°. This conclusion is amply substantiated by the dips and the distribution of formations in

the field. This major fold is modified on the northwest by a prominent subsidiary anticline to which the Edwards and Balmat mines are intimately related. Some odd features in the present interpretation, however, must be explained.

The presence of definitely synclinal characters in the folds at Edwards and Balmat seems to indicate an unusual condition. The best surface evidence that the Edwards mine is situated on a subsidiary anticlinal axis is found along line *I–H*, Fig. 1. The granite at *I* is irregularly sill-like, and its margin is closely paralleled by a thin band of gneiss interbedded in the limestone. Where the granite terminates at the northeast, this band of gneiss shows clearly its northeastward plunge at an angle of about 45°

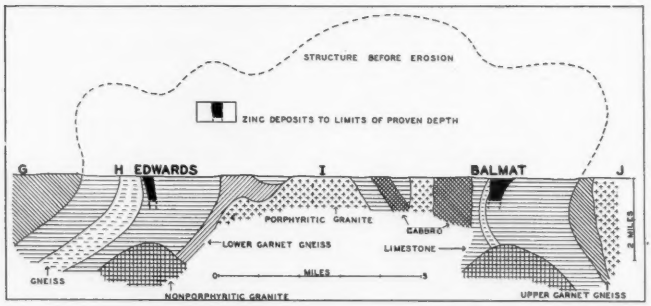

FIG. 3. Longitudinal section, Edwards-Balmat Area.

and, furthermore, shows plainly two minor crests to the anticline with a trough between.

The plunging anticline reappears a mile to the northeast in the outlier of lower garnet gneiss, which also exhibits the two anticlinal crests with intervening trough. This much of the structure was recognized by Cushing and Newland,[15] but no one seems to have noted that its continuation to the northeast is reflected in the curve of the median gneiss at the Edwards mine, which represents the western of the two minor crests of the anticline. The same crest is again reflected in the V-shaped border of the limestone near *G*.

[15] *Op. cit.*

an area very inaccurately mapped in the report on the Gouverneur quadrangle. Even the second crest and minor trough are reflected somewhat less clearly, east of *G*, but are covered by alluvium near Edwards. The axial plunge of these V-shaped folds, amounting to about 45° to the northeast at *I*, seems to be nearly 90° in the outlier of garnet gneiss, is slightly reversed, at 75° or 80° to the southwest at the Edwards mine, and is indeterminately steep, probably reversed, at *G*. In other words, a structure which began as an anticline has been overturned along its axial plunge and transformed into a pseudosyncline. This structure gives a clue to that at Balmat, which is less obvious, but probably analogous. The suggested origin of these structures is as follows:

The Edwards district is bordered on the northwest by a great elongate body of porphyritic granite which appears to have risen along the axis of a deep syncline. The pressure of the granite was particularly great against the protruding side of the dome, causing it to be rolled up into a subsidiary anticline, and permitting the granite, at its extreme advance, to invade the limestone. The excessive pressure against the plastic limestone at this point caused it to yield by flowage, pressing it upward and outward, probably for thousands of feet, into the noses of the minor anticlinal axes near Edwards and Balmat. The result was over-steepened sigmoid folds, Z-shaped in plan at Edwards, S-shaped at Balmat. The result in section along the longitudinal axis of the fold is shown in Fig. 3, and is simply that of fan-folding developed in the long axis of the fold rather than along the short axis. This steep and apparently synclinal structure in the Edwards mine has been traced to the 1500-foot vertical level, where it seems to revert to the normal anticlinal direction. At Balmat it appears to continue beyond 2,000 feet of depth.

Balmat Fault.—Faulting near Balmat is mentioned in the Lake Bonaparte quadrangle report (p. 96) and again by Buddington,[16] who noted displacement of more than a mile in the upper garnet gneiss, but did not name or map the fault. The name Balmat

[16] *Op. cit.*, pp. 79–81.

Fault is proposed for this rather obscure structure. Field evidence of faulting is shown by the displacement of the garnet gneiss and by pronounced discordance in structure between the gneiss and limestone along the line *F–F*, Fig. 1. Obvious brecciation and granulation are not conspicuous, presumably because the fault was formed at a depth where flowage was as important as fracturing. However, in its clearest exposures, for a distance of several miles, the fault zone is 200 or 300 feet wide with either minute shattering and jointing, or strong flow-banding and microgranulation of the rocks involved. There is sporadic reticulation by quartz veinlets. The displacement of the fault is probably horizontal rather than vertical, with a maximum of about 3 miles.

The writer would explain this structure as the direct result of the intrusion of the non-porphyritic granite into the outer part of the Balmat sigmoid, the granite wedge shoving the garnet gneiss northeastward, squeezing the limestone formation almost to obliteration. This explanation has been questioned, but after further investigation still seems to have much to commend it. The fault appears to die out on the northeast near *P–P*, where it may slightly displace the median gneiss; and fades out similarly about 6 miles southwest of Balmat. Here its displacement is probably in the opposite direction. It is clearly later than the porphyritic granite, but nothing in the field evidence was found to prove that it is later than the non-porphyritic granite, to which it seems closely related in origin and effects.

BALMAT MINE.

General Nature and Form of Deposit.

Owing to the prevailing shallow drift cover, the outcrop of the Balmat deposit is barely discernible at two or three places. The total length of the deposit is about 3,000 feet. The ore bodies, commonly designated "veins" in mining parlance, are actually replacements either along true bedding or modified flow banding. The northeastern portion of the deposit consists mainly of a single "vein," or ore-shoot, but the southwestern part usually

comprises at least three fairly distinct shoots, and includes the richest ore as well.

The controlling structures which govern the distribution of ore shoots at Edwards and Balmat are rather closely akin, and are compared in Fig. 4. Each mine is related to a sharply recurved fold in the median gneiss, the Edwards mine occupying the inner side of the fold, stratigraphically below the gneiss, and Balmat the outside of the fold just above that member. The sharp point into which the median gneiss has been crushed at the outer side of the fold near Edwards is typical of many structures in the region where a brittle member intercalated in plastic limestone has been closely folded. The limestone inside the brittle band has a more rounded form, but outside the fold presumably shares something of the acutely pointed structure.

This gives the clue to the form of the Balmat deposit, the essential feature of which in plan is a closely compressed V with one side elongated, or an irregular series of V-s one inside the other. In detail there are many complications of this structure. The trend or rake of the deposit, as proved to a depth of 1,500 feet or more, is north, at an average inclination of about 35°. The maximum dip, however, is to the northwest at about 45°.

Average Composition of Ore.

The composition of Balmat ore as milled for a three-day period, Oct. 31 to Nov. 2, 1933, is indicated by the table, p. 246.

The sample comprises ore from the 300-foot and 500-foot levels, but is confined to the southwest end of the deposit, where values are above average. It is unduly high in certain secondary products that are restricted to this end and to the upper 1,000 feet of depth. These include the iron oxides, the ilvaite, the chlorite and an important proportion of the sphalerite and galena, as will be described in detail in a later paper.

In addition to the minerals listed, there are traces of ore accessories, such as willemite, pyrrhotite, and chalcopyrite, and of gangue minerals such as titanite and feldspar. Sericite is absent.

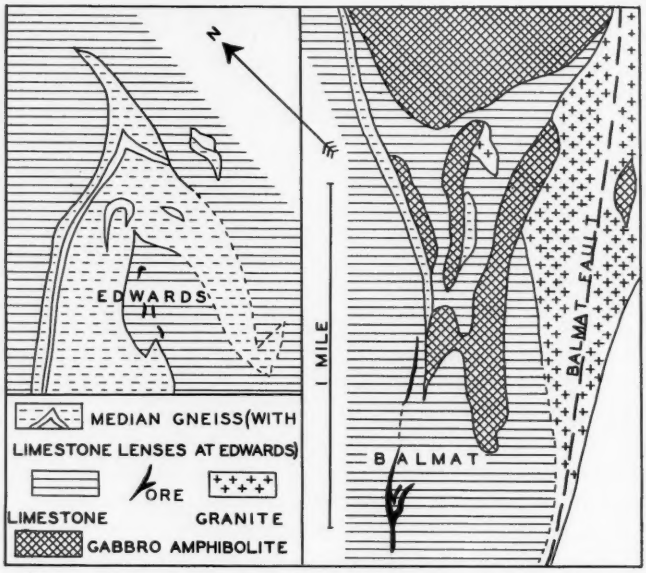

FIG. 4. Comparison of structures at Edwards and Balmat Mines.

CHEMICAL AND MINERALOGICAL ANALYSIS OF BALMAT ORE.

Chemical constituents, %		Mineralogical components, % weight	
Zn	12.02	Sphalerite	19.44
Fe	12.58	Pyrite	18.52
Pb	1.12	Galena	1.29
$BaSO_4$	1.28	Barite	1.28
CaO	14.76	Calcite and dolomite	21.84
MgO	8.46	Diopside	13.00
CO_2	9.75	Talc	6.50
SiO_2	21.86	Quartz	6.00
S (calculated)	16.57	Tremolite	3.20
O_2 (calculated)	.89	Phlogopite	2.00
		Garnet	.40
		Serpentine	Tr.
		Hematite and magnetite	3.17
		Chlorite	1.50
		Ilvaite	1.00
Total	99.29	Total	99.14

L. E. O'Neil, Balmat, N. Y., analyst. Mineralogy based on microscopic grain counts by the author, reconciled with chemical analysis.

Gangue Minerals Antedating the Ore.

Calcite or Dolomite.—Since the ore minerals, including barite, mainly replaced carbonate, and since later hydrothermal and secondary minerals also replaced it extensively, the proportion of carbonate in massive ore is small. Probably half of the carbonate in the analysis is due to dilution by wall rock and waste, which are at least 50 per cent. carbonate.

In rock not too strongly affected by silication and sulphide replacement, carbonate constitutes grains of compact form, usually 0.2 to 0.3 mm. in diameter but occasionally much coarser. Most of the carbonate is an original component, but small amounts of later generations constitute veinlets in the ore and rock. In some cases these are earlier than the ore, in others definitely later. Chemical analysis shows that at Balmat the carbonate is principally calcite, but at Edwards it is nearly pure dolomite. Magnesia is more abundant in silicate form at Balmat, however. It is believed to be mainly an original constituent.

Garnet.—Garnet is not typical of the limestone in the vicinity of the zinc mineralization, but almandite garnet zones near limestone-granite contacts are common not far away.[17] Garnet at Balmat is lemon-yellow and occurs as minute crystals, not exceeding 0.1 mm. in diameter. These are either disseminated, or in small aggregates resembling a yellow, friable sandstone. In many cases the garnet has been stained red by later hematite. In thin section many of the garnets show division into sectors and exhibit anisotropism. Supposedly this indicates a lower temperature of formation than for ordinary garnet.

Diopside.—Diopside is the most abundant and characteristic of the early anhydrous silicates, and is also common in unmineralized limestone throughout the region. By alteration, diopside has supplied a large part of the abundant talc and serpentine found in the ore deposits, and since these are largely of post-ore age, it is probable that the average rock now constituting ore contained nearly 50 per cent. of diopside when ore deposition began.

The diopside grains are inconspicuous, averaging about 0.2

[17] Buddington, A. F. *Op. cit.*

mm. in cross section. The color is faintly green or white. Isolated grains may show crystal form under the microscope; more commonly the diopside grains are irregularly intergrown with one another or with other minerals. Inclusions of unaltered carbonate, also quartz in some areas, are common. Later alteration of diopside to talc or serpentine has been so extensive that unmodified grains are seldom found.

Tremolite.—Tremolite is probably as abundant as diopside in the region, but is much less common in the zinc mines, being almost negligible in Edwards ore. At Balmat the mineral is not plentiful in the ore; the 3.2 per cent. in the analyses comes chiefly from marginal areas and development headings. The mineral is generally white and occurs in felted or fibrous forms.

Extensive bands of nearly pure tremolite rock occur within the limestone, and form the basis of talc mining in the district. The tremolite is only slightly altered to talc in most cases. It has been noted that such bands are frequently found near, but overlying, zinc deposits, and at Balmat a persistent "talc" band 10 to 100 feet in thickness parallels the ore on the hanging side at a distance of 200 or 300 feet.

Quartz.—Only traces of quartz are found at Edwards, but it is fairly abundant in parts of the Balmat mine. It is considered to be an original sedimentary constituent, like carbonate, deposited as sand grains in lenticular bands of siliceous limestone or calcareous quartzite. Circulating solutions have destroyed the sedimentary shapes so that the grains are irregular, with interstitial carbonate and silicates, or sulphides. Some quartz also may have been introduced. The best evidence of sedimentary character is in the interbedded nature of the lenses and their conformity to folded structures, as well as in the small average size and habit of distribution of quartz grains. Heavy minerals such as are typical of many sandy rocks are rare.

Mica.—Phlogopite is fairly common in some parts of the mine, and is visible as small deep-green spots. In thin section it shows roundish or bent sheaves of plates about 1 mm. in length, brown to greenish. Biotite and muscovite were not noted in the samples

of Balmat ore, as analyzed, but are abundant in certain bands of altered limestone near the ore, and form the hanging wall of part of the deposit.

Primary Ore Minerals and Related Accessories.

Pyrite.—Pyrite at Balmat occurs in grains up to a maximum of about 5 mm. in diameter. As a rule, the grains do not show crystal form, but in areas where pyrite is abundant and of coarse texture most grains show imperfect curved faces of the pyritohedron. The cube is seldom or never seen. Pyrite is irregularly distributed and certain ore shoots are extremely pyritic, with little sphalerite. This type of ore favors the siliceous bands, and here pyrite seems to have developed crystal outlines by replacement of quartz, in numerous instances. Pyrite was the earliest of the ore minerals, but probably continued to form in decreasing volume throughout most of the period of sulphide deposition. It appears to be of one generation. Even though it may replace quartz to some extent, most of it replaced carbonate, and it is commonly molded around quartz and silicates, especially diopside.

Sphalerite.—Primary sphalerite in the Edwards district is of dark chocolate-brown color indicative of its considerable isomorphous content of ferrous iron. The following analyses are from selected material, hand-picked under the microscope.

ANALYSES OF SPHALERITE.

Location	Zn %	Total Fe %	Combined Fe % (HCl soluble)	Mn %
Balmat	58.79	7.25	6.96	0.10
Edwards	60.24	5.85		0.15

Sphalerite occurs as irregular grains and ramifying aggregates, or rarely, near the margins of ore bodies, as disseminated grains 1 to 2 mm. in diameter. Where a calcareous matrix is abundant, roundish forms suggesting crystal outlines may occur. Coarse crystallinity, with cleavage faces ½ inch or more across, is com-

mon, but free crystals have not been found in normal primary ore. Sphalerite is molded around quartz and the pre-ore silicates, diopside, tremolite, phlogopite and garnet. Slight replacement of all of these probably occurred, and is definite in the case of garnet, but most of the sphalerite replaced carbonate, and the common inclusions in silicates are generally explainable as replacements of carbonate inclusions. Small specks in cleavages and fractures of silicates are abundant but volumetrically unimportant.

Sphalerite is also molded on and typically interstitial to pyrite, indicating the earlier emplacement of the pyrite. The excessively pyritic ore also implies pre-emption by pyrite of all available carbonate, leaving little room for sphalerite. In rare cases, primary sphalerite fills cracks in pyrite. The massive sphalerite at places contains small, ragged, pyrite inclusions that suggest partial replacement of pyrite, but this process almost certainly was unimportant. The high sphalerite more likely implies that ore solutions did not penetrate these areas in volume until the pyrite stage was largely past.

The amount of primary brown sphalerite in the sample analyzed is about 75 per cent. of the total, the remainder belonging to the second generation, which is considered supergene.

Three types of zinc ore may be distinguished in the Balmat mine: (1) excessively pyritic ore with siliceous gangue; (2) a very rich sphalerite type, low in pyrite, with gangue chiefly carbonate and barite; (3) an intermediate type in which both pyrite and sphalerite are abundant, and the gangue is chiefly silicates, with a little quartz. There are gradations between all three types.

Galena.—Primary galena at Balmat occurs typically as angular grains not exceeding 0.1 to 0.2 mm. across, interstitial to pyrite and sphalerite. Like the other sulphides, it is molded around the silicates as well as around pyrite. With sphalerite the contacts in some cases suggest molding of galena on sphalerite and in other cases are ragged or indefinite. It is probable that galena was deposited mainly during or just after the closing stages of sphalerite deposition. It replaced calcite mainly, but is relatively much more abundant as specks in cracks and cleavages of silicates

than is sphalerite. Rarely, galena of coarse cleavage fills fractures in brittle siliceous rock.

The distribution of primary galena is erratic. In the very pyritic ore it is about of average tenor; in the rich sphalerite ore it is virtually nil; and in the intermediate type of ore, with high silicate gangue, it is most abundant, and may give 4 to 6 per cent. Pb. Even this is inconspicuous to the eye, being masked by the more abundant sulphides. In any part of the mine where several runs of ore are superimposed, there is an almost unvarying tendency for the upper runs to be relatively low in lead. This situation is so prevalent that it was investigated to determine whether it might imply supergene enrichment of the lower bands. It was found, however, that the galena is primary, and its distribution correlates closely with the occurrence of certain favored rocks.

Many grains of primary galena are shattered along cleavages and healed with talc; galena rarely fills cracks in pyrite and sphalerite. Inclusions of galena are present, in places, as blebs inclosed in sphalerite after the manner of chalcopyrite, with which they are associated.

Secondary galena possibly accounts for one-fifth of the lead assay in the analysis of Balmat ore. Its occurrence and distribution differ materially from that of primary ore, as will be described hereafter.

Balmat galena carries very little silver, lead concentrates assaying about 10 ounces per ton.

Chalcopyrite.—Chalcopyrite in the Edwards district is a microscopic accessory of no commercial importance. Its primary occurrence is entirely as minute inclusions in primary sphalerite, the type of association ascribed by some [18] to ex-solution and by others to replacement.

Pyrrhotite.—Pyrrhotite appears in a few polished sections of Balmat ore, always associated with chalcopyrite inclusions in sphalerite. The grains of pyrrhotite generally are larger but less

[18] Bastin, E. S. et al.: Criteria of Age Relations of Minerals, with especial reference to Polished Sections of Ores. ECON. GEOL., vol. 26, p. 572, 1931. Teas, L. P.: The Relation of Sphalerite to Other Ores. Tr. Amer. Inst. Min. Eng., vol. 59, pp. 68–82, 1918.

numerous. Chalcopyrite may partially or completely encircle the pyrrhotite grains, as if it were later. Pyrrhotite is considerably more abundant in Edwards ore, but chalcopyrite is less plentiful than at Balmat.

Barite.—Barite is an accessory of more importance than the analysis (1.28 per cent.) indicates because it has been replaced extensively by talc and by secondary minerals such as chlorite, hematite and sphalerite. Barite replaced carbonate almost exclusively. Since it followed the sulphides, it can only be abundant where unreplaced carbonate remained in considerable amount. For that reason it is most abundant in the rich sphalerite type of ore, and in some cases exceeds 20 per cent. of the rock by volume. Barite also occurs to some extent in the wall rock beyond the ore.

Barite has an interstitial relation to primary sulphides, pre-ore silicates, and quartz. For this reason the grains commonly are not large, and crystal forms are not prominent. However, where the carbonate masses were large, bladed barite forms, 1 to 2 mm., or occasionally 1 cm. in length, developed. Replacement of barite by talc and other minerals commonly proceeded along cleavages, and in some cases produced pseudomorphs after the bladed barite. In rare instances barite fills cracks in pyrite and sphalerite. It occupies the time interval at the close of primary sulphide deposition and preceding hydrothermal alteration.

Anhydrite-gypsum.—A single thin section of Balmat ore contains anhydrite in relations which appear to be identical with those of barite.[19] It is interstitial to sulphides, fills cracks in sphalerite, and is replaced by talc, or altered into gypsum along contacts with talc. The gypsum should probably be regarded as a hydrothermal alteration product.

Diamond-drill cores supply several occurrences of gypsum in limestone at considerable distances from ore. Thin sections commonly show some anhydrite from which the gypsum has been derived, and indicate that the anhydrite replaced carbonate. Small cavities, probably of supergene origin, are commonly asso-

[19] Butler, B. S.: Primary (Hypogene) Sulphate Minerals in Ore Deposits. ECON. GEOL., vol. 14, pp. 581–609, 1919.

ciated with these gypsum occurrences. The gypsum in one case veins carbonate, anhydrite and talc, and may well be a superficial alteration product of anhydrite, rather than hydrothermal. The anhydrite in these cases may or may not be related to the period of ore deposition. Gypsum of deep-seated origin is a post-sulphide associate of Edwards ore.[20]

Post-ore, Hydrothermal Alteration Products.

Talc.—Talc is the most abundant of the deep-seated alteration products. It has commonly been regarded as derived mainly from tremolite, and in the talc mines that may well be true. In both Balmat and Edwards ore, however, talc was derived mainly from diopside. In the early stages it formed along cleavages and cracks, finally completely replacing the diopside, and beyond that it has been widely distributed as a replacement of carbonate and barite and a filling of cracks in sulphides. This outward migration is probably an effect of the increase in volume that should accompany a change from the anhydrous to the hydrous silicate.

The talc at Balmat occurs as aggregates of fine flakes, with a range of color from clear or dusty to greenish and even brown. The colored varieties verge toward chlorite, and much chlorite undoubtedly is a result of conversion of talc, by processes believed to be mainly supergene. The talc, as indicated by its persistence in all areas and to all depths, evidently is hypogene.

Serpentine.—The amount of the serpentine in the analyzed sample is surprisingly small, inasmuch as the mineral is abundant in the wall rock at many places. It also appears in thin sections of the ore from the northeast end of the ore body, an area not represented in the sample. At Edwards serpentine is more abundant than talc.

Serpentine occurs as small green or yellow-green spots. Like talc, it is a product of the alteration of diopside and has also spread widely, replacing carbonate. Like talc, serpentine fills cracks in sulphides; it is also widely distributed beyond the limits of ore.

[20] Brown, John S.: *Op. cit.*

Age of Talc and Serpentine.—It has been argued by some [21] that the talc and serpentine are chiefly products of a pre-ore alteration period, since they correspond in their widespread distribution with the pre-ore silicates, tremolite and diopside. This view seems to have been favored in some degree by Smyth,[22] who, however, could only find definite evidence that some of the talc and serpentine was later than the ore. At Balmat the evidence seems clear to the writer that most if not all of the talc is later than the ore. The following points are cited.

1. Talc extensively replaces post-sulphide barite.

2. Numerous cracks in pyrite and sphalerite are filled with talc and much primary galena is split along cleavages and filled with talc.

3. Selvage films of talc abundantly encircle pyrite, and frequently also sphalerite, as if talc-depositing solutions had circulated about the margin of the sulphides.

Depth Variations of Ore.

Considerable chemical and mineralogical information has been assembled for the three zinc properties of the district which have been operated commercially, the object being to study the nature of any possible vertical zoning or variation with depth.

Edwards Mine.—The Edwards mine is opened to much greater depth than the others and has the longest record of experience. The following chemical analyses of the crude ore are of interest.

Column A is the actual analysis for 1933 ore: In A′ this is recalculated to a basis of 20 per cent. Zn on the assumption that Zn, Fe, Pb and S would retain their respective ratios, increasing wholly at the expense of (Ca, Mg)CO_3, an assumption believed to be nearly correct. Column A′ is more readily compared with B and C. Mill heads were richer in 1916, chiefly because economics and mining methods were different.

It appears that the ratios of sphalerite, pyrite, galena, and even barite have remained virtually unchanged. To confirm this, it

[21] Spurr, J. E.: *Op. cit.*

[22] *Op. cit.*

CHEMICAL ANALYSES OF EDWARDS MILL HEADS.

	Nov., 1933. Three days		*1916. One month each* [23]	
	Ore chiefly from 1300–1500		Ore from 300 or above	
	A	A′	B	C
Zn	12.12	20.00	21.47	18.52
Fe	5.59	9.22	8.50	8.46
Pb	.10	.165	.125	.197
S	10.05	16.58	19.01	17.18
$BaSO_4$	2.54	2.54	2.75	1.52
CaO	20.58	15.08	9.34	11.76
MgO	15.62	11.69	13.17	15.04
CO_2	19.98	11.31	N.D.	N.D.
SiO_2	12.80	12.80	10.67*	12.12*
Al_2O_3	Tr.	Tr.	4.17	1.98*

[23] Cushing and Newland: *Op. cit.*, p. 92. See also Newland, *Op. cit.*, 1917. The three starred figures are here corrected, being in error in the published reports.

should be added that visual and microscopic comparison shows these minerals in substantially the same form at higher and lower levels. The most important difference is in the moderate alumina in B and C, which is almost certainly due to contamination with infiltrated surface mud near the outcrop.

Balmat, Edwards and Hyatt.—At Balmat the only information regarding the deeper ore is that from drill holes, a considerable number of which intersect ore at depths between 1,000 and 2,000 feet. Visual and microscopic examination indicate no striking change in the character of primary ore from the surface to the greatest explored depths.

The comparison is complicated somewhat by the fact that surface waters have affected the ore considerably on the upper levels. In the following table, mineralogical analyses of Balmat ore from higher and lower levels are compared with each other and with Edwards and Hyatt ore.

For Hyatt, G is the actual analysis and G′ is a recalculation in which the sulphides have been reduced by 40 per cent. and the chief gangue minerals correspondingly increased. Column G′ is more readily compared with the remaining analyses. There

MINERALOGICAL ANALYSES OF BALMAT, EDWARDS AND HYATT ORE.

	Balmat *November, 1933*		Edwards *November, 1933*	Hyatt Dump	
Three days mill heads. Above 500		Composite drill hole sample. 1000–2000	Three days. 1300–1500	Mostly from around 300 ft.	
	D	E	F	G′	G
Sphalerite	19.44	25.62	19.66	21.90	36.50
Pyrite	18.52	53.30	6.61	13.90	23.20
Galena	1.28	2.34	.12	.02	.03
Barite	1.29	2.16	2.54	.28	.28
Dolomite	21.84		43.23	38.30	24.00
Diopside	13.00	(Insol., 12.90.	7.00	1.50	.90
Tremolite	3.20	Undetermined,	Tr.		
Talc	6.50	chiefly	6.23	12.00	7.50
Serpentine	Tr.	Ca, $MgCO_3$,	12.74	8.30	5.20
Quartz	6.00	3.68)	1.50		
Phlogopite	2.00			3.20	2.00
Garnet	.40				
Secondary minerals (chlorite, ilvaite, magnetite, hematite)	5.67	None			
	99.14		99.63	99.40	99.69

is no reason to believe that Hyatt ore is richer than Edwards or Balmat ore.

The 5.67 per cent. of secondary minerals in D was deposited at the expense of pyrite, talc, barite, carbonate, and serpentine which were present in the original ore. In addition, almost one-fourth of the sphalerite and galena are secondary and were deposited at the expense of much the same minerals. Therefore, the primary ore at Balmat would have contained between 20 and 25 per cent. pyrite, probably 3 per cent. barite, and moderately greater amounts of dolomite, diopside, talc and serpentine. Allowing for differences due to superficial alteration, there is not much evidence of any important change in the character of Balmat ore down to about 2,000 feet, unless perhaps an increase in pyrite. Sample E, it may be noted, contained no waste.

The three properties seem to exhibit certain persistent minor differences. Balmat contains excessive pyrite, Edwards much

less, and Hyatt intermediate. Barite is much the same at Balmat and Edwards, and almost absent at Hyatt. Galena is important at Balmat, is present in traces at Edwards, and is virtually nil at Hyatt. Comparing gangue, carbonate is substantially identical at Hyatt and Edwards, low at Balmat. In part, this is the inverse result of the abundance of pyrite at Balmat, more carbonate having been replaced; in part, it is the reflection of the superabundance of silicate gangue at Balmat. Hydrothermal alteration of the pre-mineral silicates is least at Balmat and virtually complete at Hyatt.

Origin of Ore.

The writer's opinion as to the origin of the zinc ores is entirely in agreement with that previously expressed by Smyth and Newland, who believe that the ore solutions were derived from underlying igneous masses. Further than this, it seems likely that the igneous source was one of the two pre-Cambrian granites, more likely the non-porphyritic phase, since ore has lately been found replacing pegmatite at Edwards. It is suggested that the deposits have their source in masses of the supposedly later granite which are deeply buried, as shown in Figs. 2 and 3. The actual depth to granite may be much greater, or possibly less, than conjectured.

It is also possible that the ore was not given off directly by the granite, but by some unusual local variant which split off the granite in its cooling stages. The abundance of granite compared to zinc deposits, taking this region and related parts of Canada into account, indicates that other requirements besides the presence of granite are essential. One necessary feature seems to be a limestone host, but limestone is also so abundant compared to zinc that other limiting factors are implied. Doubtless depth is one. Very likely some zinc deposits exist which have not been exposed by erosion, and others are entirely gone.

It seems certain that the deposits were formed at greater depth than is usual for deposits of their composition. That conditions so deep within the earth's crust could have been sufficiently uni-

form to produce an almost unvarying type of ore over a vertical range of thousands of feet is remarkable.

The habits of replacement and the relation of ore shoots to bands of more than average permeability indicate that the solutions were quite fluid. The sequence of the ore minerals from pyrite through sphalerite and galena to barite and anhydrite suggests that they were acid and predominantly of sulphate character. At first they were highly concentrated, but as the metallics were deposited and temperature presumably fell, they became relatively or actually more aqueous, as indicated by the formation, in the final stages, of hydrous minerals such as talc, serpentine, and gypsum.

St. Joseph Lead Co.,
Edwards, N. Y.

A CONTOUR METHOD OF REVEALING SOME ORE STRUCTURES.

H. J. C. CONOLLY.

THE contour method described here is being developed and employed in the examination of a number of old gold mines [1] in Australia. The work is being done for the Western Mining Corporation and the author is indebted to the Corporation for permission to publish the material in this paper. He is also under considerable obligation to Mr. J. D. Campbell, who prepared the accompanying illustrations and advanced constructive criticism of the manuscript. The illustrations and their notes amplify and explain the text, so that a careful study of the figures is necessary in order to understand the contour method and its employment.

As is well known, the concentration of gold is commonly related to the changes in attitude of the host vein, lode, or formation.[2] There are many excellent examples of this relationship in Australia. Commonly, ore is confined to a local flattening of the reef, the change in dip being generally associated with a change in strike. In a few simple cases the ore shoots occupy only those sections of the vein with a particular strike and dip. Essentially, however, the metal concentration is not attached to any particular strike and dip, but is indeed widely related to the whole pattern of changing attitudes, the changes of attitude reflecting the governing structures.

Some connection between the "anatomy" of a vein and its gold content is what might be expected. The vein pattern is determined by the rock environment and structure and by the interplay of shear, tension and compression involved in all faulting and folding movements. The same environment, structure

[1] Most of these old mines are today full of water.

[2] Reference hereafter to vein or reef implies, where necessary, "host vein, lode or formation."

and stresses govern the deposition of gold and open the channels occupied by the ore shoots and followed by the ore solutions. Whatever controls the deposition of gold must as a rule also be reflected in the vein structure.

In the examination of these Australian mines it was found

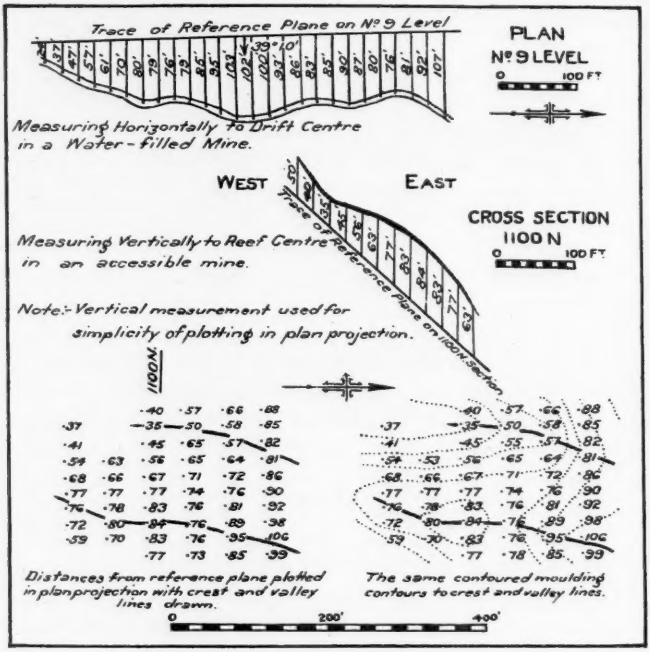
Trace of Reference Plane on No 9 Level
PLAN
No 9 LEVEL
0 100 FT
Measuring Horizontally to Drift Centre in a Water-filled Mine.
WEST
EAST
CROSS SECTION
1100 N
0 100 FT
Measuring Vertically to Reef Centre in an accessible mine.
Trace of Reference Plane on 1100N Section
Note:- Vertical measurement used for simplicity of plotting in plan projection.
1100N.
Distances from reference plane plotted in plan projection with crest and valley lines drawn.
The same contoured moulding contours to crest and valley lines.
0 200' 400'

FIG. 1. The vein-contouring procedure.

that the full significance of the relationship between vein structure and gold was quite inadequately portrayed or even not revealed by the ordinary mine plans, sections and models prepared. To learn the structure in these cases and in similar deposits, it is necessary to see its whole pattern, including the slightest changes in strike and dip, exaggerated without distortion, and to see it in

three dimensions at a glance, on one plan. This is made possible by the simple expedient of contouring the vein with reference to inclined planes which approximately parallel its average strike and dip. The contours so obtained are then superimposed on plans showing the distribution of gold through the deposit and, taking the study further, also on plans showing the distribution of quartz. Each vein in a vein assembly is treated separately.

The vein-contouring procedure is illustrated in Fig. 1. The trace of the reference plane on the mine-level plan or mine section is drawn. The distance between the reference plane and vein (or drift) center or vein wall is then measured, usually at intervals of twenty feet. Plan or vertical projections are employed for contouring, the distances being written on the projection of the vein position measured. Where the vein is shown on a mine-level plan, the measurements are made horizontally along any convenient direction, usually one of the mine co-ordinates. Where cross sections of the vein are employed, the measurements are made vertically if contouring in plan projection, or horizontally if contouring in vertical projection. Finally, the distances between reference plane and vein (or drift) are contoured in exactly the way in which topography and structure are contoured with reference to a horizontal plane. Crest and valley lines, linking the longest and the shortest distances, are drawn ahead as far as possible to guide contouring, the relatively uniform "gradient" along these lines affording the best locus for the proportional spacing of the contours. These crest and valley lines mark the changes in vein strike and dip and are therefore the most important features of the plan. In water-filled or inaccessible mines, where only old level plans are available, the most careful contouring is necessary to gain any reliable idea of the flatter pitching structures.

The first step in a mine study is to establish whether there is or is not any connection between vein structure and gold (and quartz). This is most safely tested by contouring the vein with reference to an arbitrarily chosen inclined plane, say a plane which parallels the average strike and dip of the most important ore

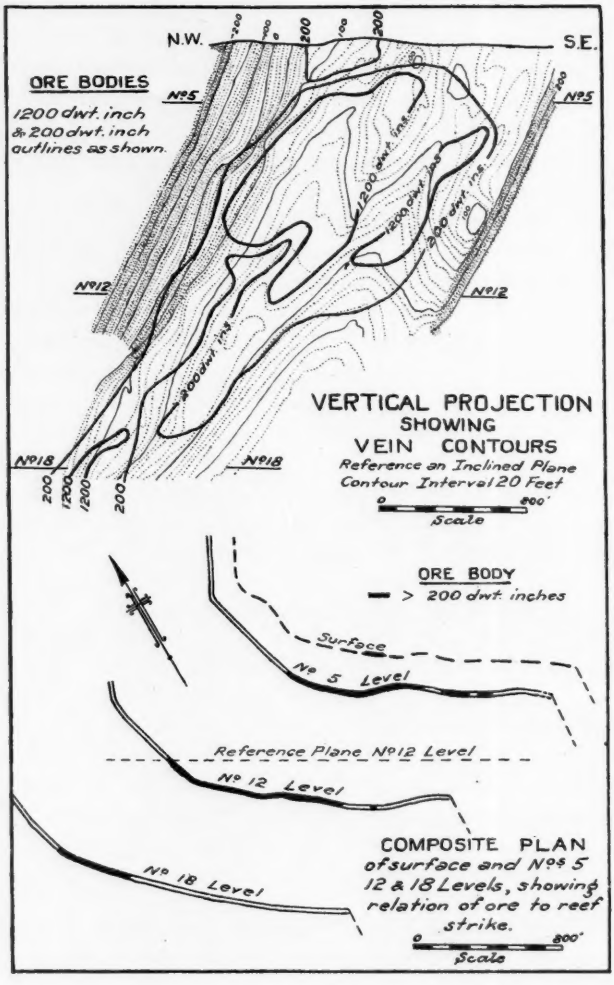
N.W.
S.E.
ORE BODIES
1200 dwt. inch & 200 dwt. inch outlines as shown.
No 5
No 12
No 18
1200 dwt. ins.
200 dwt. ins.
VERTICAL PROJECTION SHOWING VEIN CONTOURS
Reference an Inclined Plane
Contour Interval 20 Feet
0 800'
Scale
ORE BODY
> 200 dwt. inches
Surface
No 5 Level
Reference Plane No 12 Level
No 12 Level
No 18 Level
COMPOSITE PLAN
of surface and Nos 5 12 & 18 Levels, showing relation of ore to reef strike.
0 800'
Scale

FIG. 2.

shoot or of the richest portion of the vein. Figures 2 and 3 illustrate two preliminary tests. As in these instances the coincidence between gold (or quartz) and structure, if any, becomes immediately apparent. With some coincidence proved, the vein contouring is repeated, employing carefully chosen reference planes which will

(*a*) permit of the maximum extrapolation of the vein structure, employing to best advantage the positions given by the remoter reef outcrops and intersections in drill holes and crosscuts. For extrapolation, ridge and valley forms are more serviceable than terraces. In some instances it is necessary, by changing the reference plane, to subdue some of the prominent features which would otherwise mask or conceal the slighter but often equally important structures.

(*b*) resolve the vein structure into a pattern of intersecting loci seen on the contour plans as intersecting ridges and valleys. In most cases there are two or more such loci related to the distribution of gold (and quartz). The theme of intersecting loci in mineral deposits is a familiar one. Ore bodies may form only at their intersections; shoots may follow one locus under certain conditions and another under other conditions, etc.

This selection of reference planes to suit the problem opens a wide field of possibilities, for the plane employed largely determines the spacing of the contours and the actual position and

FIG. 2. Preliminary contour test of the Great Fingall Mine, Cue, Western Australia.

In this quartz vein the ore body, pitching southwest, is entirely confined to the middle limb of a prominent S structure. Contouring shows that this middle limb includes three inconspicuous but similar S bends. From the surface to the 5-level the whole ore limb rotates in plan slightly and relatively anti-clockwise. From the 5- to the 12-level the limb remains in the same relative position of a pronounced S structure, while below the 12 it rotates back slightly and relatively clockwise. The one prominent S structure, with its three inconspicuous but similar structures, and the rotation of the ore limb, are closely related to the distribution of gold. The S bends provide the loci of the whole deposit and the three component ore shoots. The shoots are small and poor where the whole ore limb is rotating anti-clockwise or clockwise, and very large and rich where and only where the ore limb remains in the position of a pronounced S structure between the 5- and 12-levels. In a case like this two drill-hole intersections defining the strike of the reef in unexplored ground would provide information of vital importance in the search for further ore. Note: This mine today is full of water.

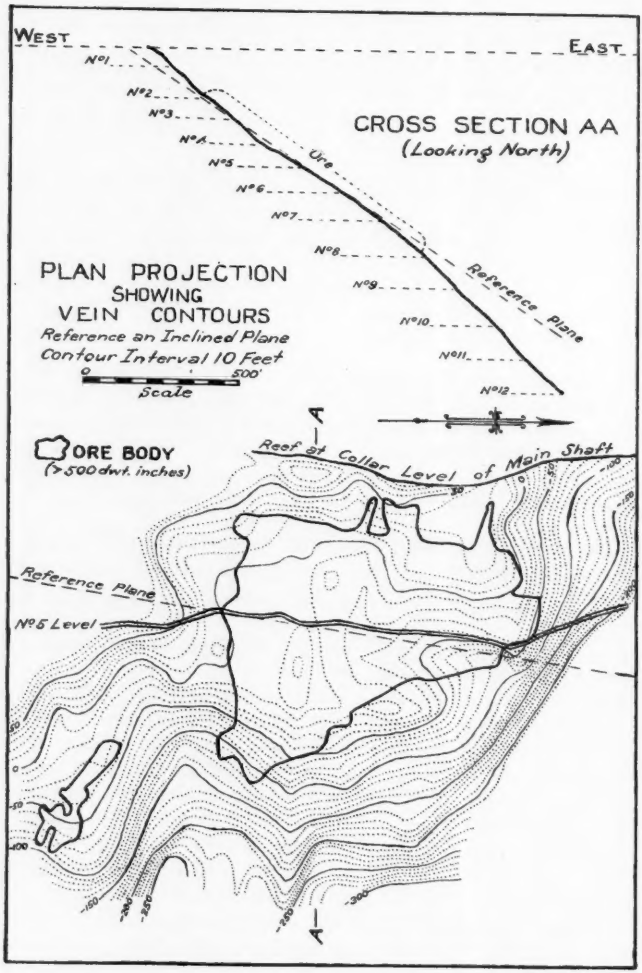
WEST
EAST
No1
No2
No3
No4
No5
No6
No7
No8
No9
No10
No11
No12
Ore
Reference Plane
CROSS SECTION AA
(Looking North)
PLAN PROJECTION
SHOWING
VEIN CONTOURS
Reference an Inclined Plane
Contour Interval 10 Feet
0
500'
Scale
ORE BODY
(>500 dwt. inches)
Reef at Collar Level of Main Shaft
Reference Plane
No5 Level

FIG. 3.

course of the crest, valley and terrace lines. The moulding of the contours to serve a purpose, while difficult and laborious, is a most essential step, especially where the structure-gold relations will be employed to guide exploration. It necessitates generally a thorough knowledge of the vein structure in plan and section. To date, the selection of reference planes remains very much a process of trial and error. The best planes strike and dip as far as possible between the favorable ore-bearing and the unfavorable barren attitudes. Figures 4 and 5 illustrate the contouring of two quartz veins with reference to planes selected to permit of maximum extrapolation and to resolve the pattern into intersecting ridges and valleys.

With this special attention to vein structure, equal attention must be given to the portrayal of the gold distribution through the deposit. Old stope outlines may be very unsatisfactory and even misleading. The gold contouring procedure is illustrated in Fig. 6. Assay data is employed as far as possible, the gold being measured for contouring in dwt.-inches or dwts. Owing to the erratic distribution of the metal through most deposits, it is probably better and easier to contour the total amount of gold or average gold value in a unit block, measuring say 400 square feet by vein width. In the present work there has not been sufficient information to permit this employment of unit blocks. The amount of gold or average values across the vein at the point sampled has been used (as in Fig. 6) with, on the whole, satisfactory results. In the contouring, two gold contours are employed, the higher, a figure representing about 80 to 90 per cent of the mine average and the lower, a figure approximating the limit of profitable material. The interpolation of the whereabouts of higher grade ore is exceedingly important, for if the contour intervals are well chosen, the higher contour alone may

FIG. 3. Preliminary contour test of the Cosmopolitan Mine, Kookynie, Western Australia.

This illustrates a relationship different from Fig. 2 but equally delicate, between vein structure and gold. The quartz reefs here are controlled by an intricate pre-gold fault pattern with a large number of acute fault intersections. The ore shoots are found only on the faults striking N. and NE. and are especially developed where the whole vein system dips more flatly. Note: This mine today is full of water.

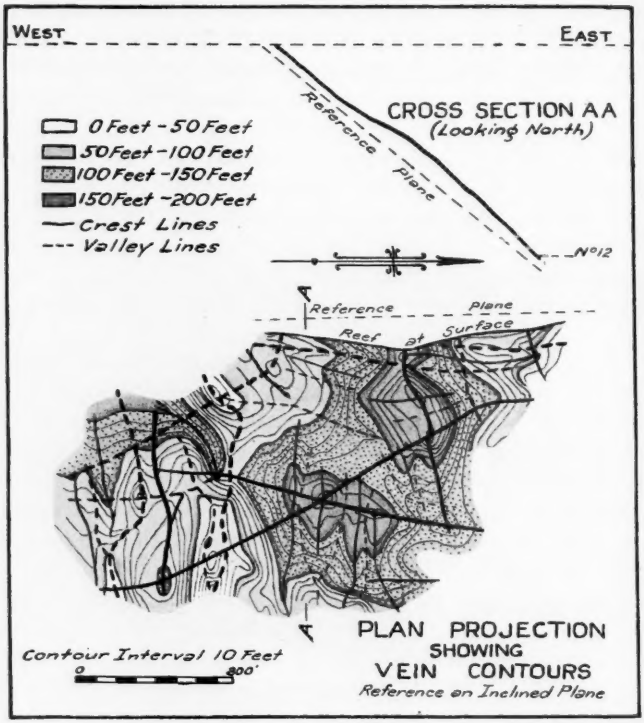

FIG. 4. Final contour test of the Cosmopolitan Mine, Kookynie, Western Australia. This figure shows the final contouring of the same vein illustrated in Fig. 3, to permit of extrapolation and to resolve the pattern into one of intersecting ridges and valleys. Comparison of the two figures reveals the important part played by the reference plane chosen and by careful contouring. Weeks of preliminary study were necessary to produce Fig. 4.

indicate the ore structure and the further extension (or repetition) of the whole deposit. In the gold plan illustrated in Fig. 8, the flat lensing of higher grade material provided the first evidence

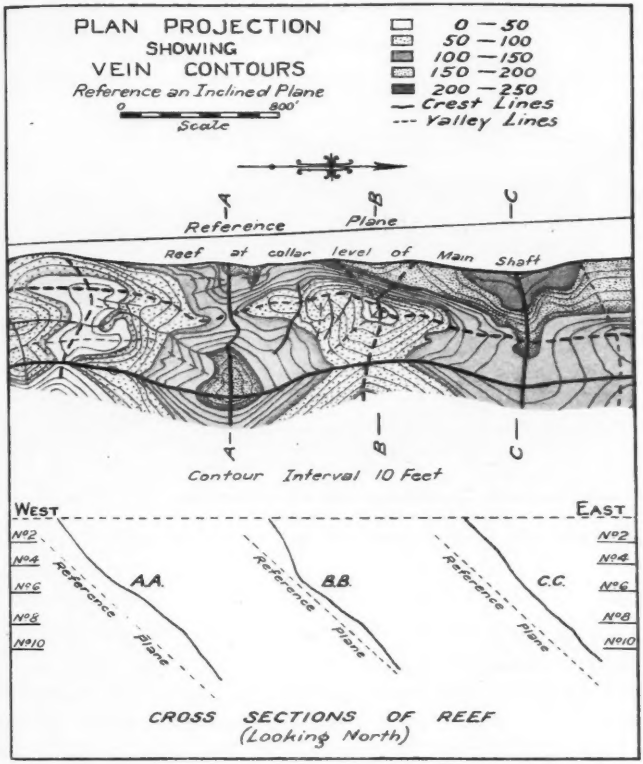

FIG. 5. Final contour test of Mararoa Mine, Norseman, Western Australia.

The plan projection shows broad, evenly spaced ridges and valleys running east and west (down the dip), intersected by a set of narrow spurs and re-entrants trending north and south (with the strike of the reef). The north-south features define, in section, an inconspicuous S-structure whose middle limb pitches flatly north. The same limb includes similar but much smaller structures seen in an alternate flattening, steepening and flattening of the reef. The S bends are relatively pronounced in the east-west valleys, while to a varying degree they are ironed out (but still traceable by contouring) across the east-west ridges.

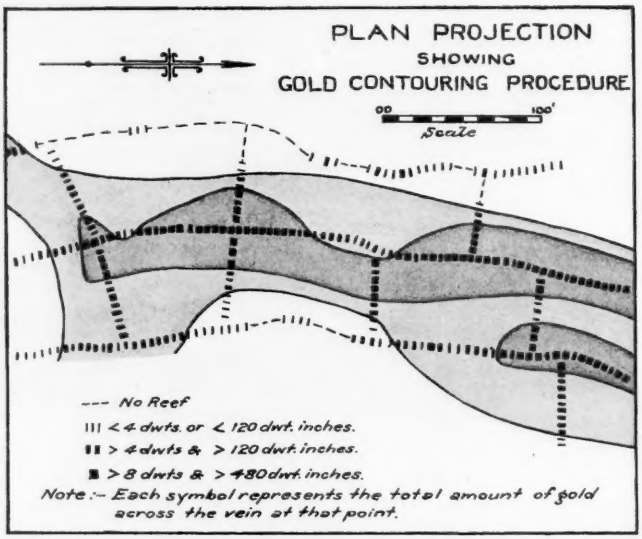
PLAN PROJECTION
SHOWING
GOLD CONTOURING PROCEDURE
0 100'
Scale
--- No Reef
III < 4 dwts. or < 120 dwt. inches.
II > 4 dwts & > 120 dwt. inches.
I > 8 dwts & > 480 dwt. inches.
Note :- Each symbol represents the total amount of gold across the vein at that point.

FIG. 6. The gold-contouring procedure.

of the flat pitch of the whole ore zone, an extension quite unexpected because of the steep south pitch of the old stopes.

In the study of auriferous quartz veins, plans are also prepared showing the distribution of quartz through the deposit. Figure 8 shows a quartz plan, the quartz being contoured in exactly the same way as gold.

Finally, the vein contours are superimposed on the gold and quartz plans, the combination showing the relationship between vein structure and gold and between vein structure and quartz. Figure 7 shows the crest and valley lines of vein contours superimposed on the gold plan of that mine. Figure 8 illustrates another mine study with structure lines added to both gold and quartz plans. In both cases the pattern of intersecting ridges and valleys explains to a remarkable and serviceable degree the distribution of gold (and quartz) in the deposit.

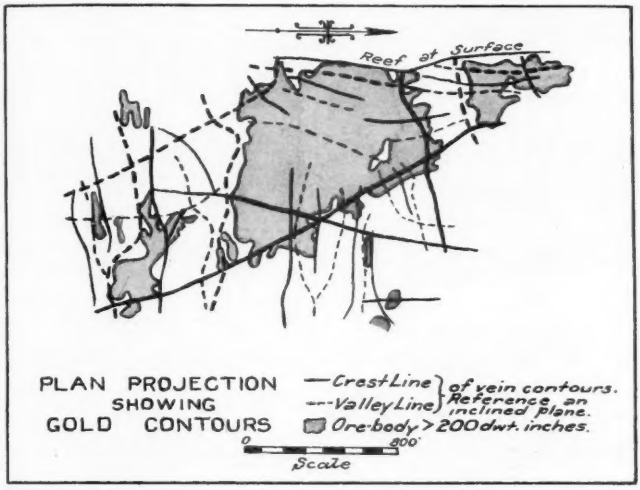

FIG. 7. Final structure-gold plan of the Cosmopolitan Mine, Kookynie, Western Australia.

Figure 4 showed the final contouring of a quartz vein. This figure shows the crest and valley lines of these contours superimposed on a plan showing the distribution of gold through the deposit. There are three ore-governing loci: (*a*) Western slope of a broad ridge trending north-west; (*b*) southern slope of a ridge-valley set running east-west; (*c*) crest and valley lines trending east of north.

Except for small unimportant concentrations of gold with some of the east-west ridges (*b*), the ore is assembled in a south-pitching zone following locus (*a*). Relatively small ore shoots are developed in this horizon where crossed only by the loci (*b*). The larger and richer main ore body fills the western slope of the north-west ridge (*a*) where crossed by a wide southern slope of an east-west ridge (*b*), and where loci (*a*) and (*c*) combine to flatten the dip of the reef. The important lines of loci (*c*) mark in places vein intersections affecting the concentration of gold, with the result that these crest and valley lines do not limit the distribution of ore as sharply as loci (*a*) and (*b*).

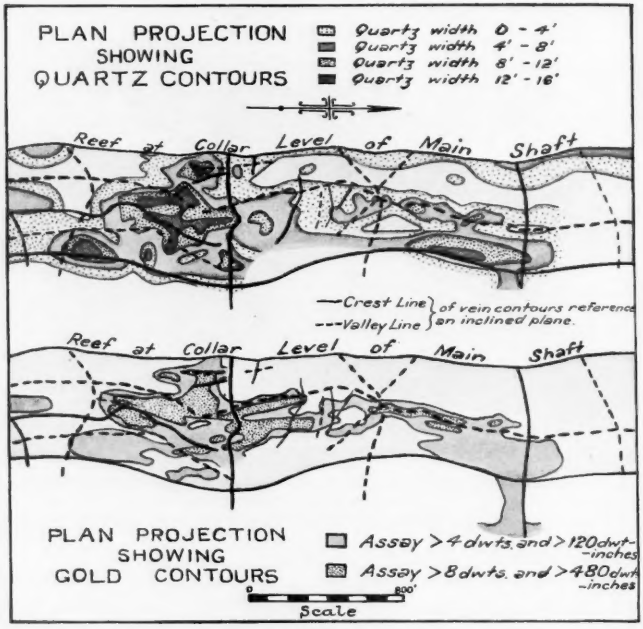
PLAN PROJECTION
SHOWING
QUARTZ CONTOURS
Quartz width 0 - 4'
Quartz width 4' - 8'
Quartz width 8' - 12'
Quartz width 12' - 16'
Reef at Collar Level of Main Shaft
Crest Line
Valley Line
of vein contours referenced to an inclined plane.
Reef at Collar Level of Main Shaft
PLAN PROJECTION
SHOWING
GOLD CONTOURS
Assay > 4 dwts. and > 120 dwt.-inches
Assay > 8 dwts. and > 480 dwt.-inches
Scale

FIG. 8. Final structure-gold and structure-quartz plans of the Mararoa Mine, Norseman, Western Australia.

Figure 5 showed the final contouring of a quartz vein. This figure shows the crest and valley lines of these contours superimposed on the gold and quartz plans of the mine. One ore extension is confined by the north-south spurs and re-entrants which define the middle limb of the S structure (see legend, Fig. 5). Another ore extension follows the east-west ridges. Where the S structures are relatively pronounced, *i.e.* in the east-west valleys, the ore body breaks down into strands following the component smaller bends; where the north-south features are ironed out, *i.e.* on the east-west ridges, the strands coalesce, the ore expanding up and down the vein dip following the loci of the east-west ridges. The north-south features, where they remain at all prominent, dominate the control. The interplay of these north-south and east-west influences and the masking of one by the other are the essential features of an intricate relationship. These structure-gold relations guided the diamond drilling of the reef, the extrapolation of the vein contours being advanced as hole intersections were obtained.

In conclusion, the contour method described reveals in an impressive way the changing attitudes of a vein, lode, or formation, and has shown in the instances studied a surprisingly accurate and delicate control of the distribution of gold and quartz. Extrapolation of the structure-gold relations so observed also provides a practicable means for promoting and guiding exploration for the extension and repetition of known deposits. To date, the work of the Western Mining Corporation along this particular line has advanced sufficiently to launch exploration in the vicinity of two abandoned mines and to complete a diamond-drilling campaign in the vicinity of a third. In each case the warranty to explore and the value of the prospect depended on the gold-structure relations discovered; in each case new ore has been found. This contour technique should also be capable of wide employment in many of the geometrical problems of ore deposits —the interpolation of mine sections, walls of sulphide bodies, faults, rock contacts and rock folds.

WESTERN MINING CORPORATION,
KALGOORLIE, AUSTRALIA,
Oct. 2, 1935.

THE INVESTIGATION OF THE CLEAVAGE OF GRANITES.

JAMES FORBES BELL.

INTRODUCTION.

GRANITE has for years been discussed by geologists and engineers, and many petrographic and chemical analyses of it have been made. However, the studies of other properties of granites, namely; jointing, cleavage (rift, grain, and hardway), sheeting or " onion " structure, faser, or " fabric," according to Sander's terminology, and various physical properties such as cohesion, elasticity, and compressibility, have not led to clarifying results.

Several recent publications on granite have made use of various new methods and ideas, but not one of these studies has employed all these methods, and many seem to have been carried out in ignorance of similar experiments in which different types of analysis were employed.

This paper presents the results of such methods for comparison and criticism. It is hoped that it will act as a guide for future investigators by mentioning much of what has already been done and by suggesting various types of procedure which, if used in all granite studies, should enable a correlation of their results and thus lead to more progressive steps in our knowledge of granites.

CLEAVAGE, SHEET, AND JOINT STUDIES.

One of the earliest experiments with granite was the investigation of its cleavage, known to the quarry workers as the rift, grain, and hardway. It was first mentioned in 1778 by Charpentier, who attributed the rift to a parallel arrangement of the mineral particles. Since then, in the opinions of various authors, it has been attributed to:—crystalline action at the time of con-

solidation; local differences in cohesion; a parallelism of the cleavage planes of the feldspars; original arrangement of the particles by flowage; pressure from only one side that did not find adequate relief in jointing; a primary effect of compressive strain; microscopic faults that follow the feldspar cleavage; fluid inclusions; cracks in the feldspars; and most recently, Osborne (5) [1] has attributed it to cracks in the quartz. The present writer, however, has shown by statistical measurements that in a granite from Büchelberg in the Bavarian Forest the rift is due to parallel arrangement of the micas (1). Any of the above-mentioned theories may be correct for some granites; but as yet, there is very little statistical data to support many of them.

Another point that has been under discussion since 1803 is the pseudo-stratification of granite known as sheeting or "onion" structure. Dale, in his bulletin on the commercial granites of New England (4), lists the following possible causes as a result of over a century's study by American and European geologists:

1. Expansion caused by solar heat after exposure of the granite by erosion.
2. Contraction during cooling, while under vertical pressure of overlying rocks; the sheets being, therefore, approximately parallel to the original contact surface of the granite.
3. Tensional strain during cooling, finding relief in the direction of the rift.
4. Expansive stress or tensile strain brought about by the diminution of the compressive stress in consequence of the removal of the overlying material.
5. Concentric weathering due to original texture or mineral composition.
6. Compressive strain akin to that which has operated in the folding of sedimentary beds.
7. Causes named under (1) at the surface, but the cause named under (6) lower down.

[1] Numbers refer to the corresponding references in the bibliography.

Recently, Blackwelder (2), reviving an idea originally proposed by James D. Dana, attributed sheeting to the hydration of the feldspars.

From the foregoing, it is seen that the definite causes of cleavage and jointing remain unsolved. Because of the lack of accurate statistical data on the part of many authors, it is almost impossible to correlate or evaluate their results.

PETROFABRIC STUDIES

By means of the new methods of petrofabric analysis introduced by Sander and Schmidt, it is possible to determine a non-isotropic fabric even in those rocks that have no visible "direction." By means of the methods set forth in Sander's book, Gefügekunde der Gesteine (8), it is possible not only to measure statistically the relative position of the mineral particles by the use of the universal stage, but also to obtain some ideas about the stress-strain conditions that have existed in the rock.

Two recent studies of granites have applied petrofabric analysis. Maroscheck (6) in 1930 used Sander's method of petrofabric analysis on some granites in Austria. By plotting the joints on an equal-area stereographic net, similar to that used in the fabric analysis, he was able to correlate the jointing and the rock fabric. He says, "The jointing and the rock cleavage have a definite relation to each other. . . . The universal-stage analysis showed an arrangement of the biotite and the quartz and proved that there is a definite relation between the arrangement of the biotites and one of the two predominant jointing systems."

The author, in his work on a granite from the Bavarian Forest, also found that the jointing and cleavage systems can be correlated with the parallel arrangement of the micas as shown by petrofabric analysis. Both of these articles based upon statistical measurements stand as direct contradictions to Osborne's statement that the rift, grain, and hardway in the Laurentian granites are not related to the jointing.

At Professor Sander's suggestion, the author also carried out

statistical measurement of cracks or ruptures by means of the integrating stage. By following along the cracks with an integrating stage and using the various spindles to indicate whether the cracks are inter- or intra-granular, and, if intragranular, which minerals they cross and whether or not their direction through these minerals was determined by some crystallographic property of the mineral, fairly accurate data about the paths of the ruptures were obtained. This method does away with approximate statements as to whether there are more ruptures in the feldspars than in the quartz, and vice versa, upon which some authors have based their conclusions.

STUDIES OF CRUSHING STRENGTH AND OTHER PROPERTIES.

Ever since granites have been used for building purposes, their crushing strength has been investigated, and it has long been known that some granites are stronger when the force is applied perpendicular to the rift than when it is applied parallel to the rift. It was not until 1929, however, that Sander, Felkel, and Drescher (9) made exact measurements of the influence of mountain-making forces and the resultant rock fabrics on the crushing strength of rocks. They determined, by investigation of a megascopically isotropic Alpine marble, that it has in reality non-isotropic fabric. This fabric caused differences of 352 kg./cm.^{2} in the crushing strength of the marble according to whether the pressure applied to the fabric was perpendicular, parallel, or oblique.

The author (1) has shown that in the case of one granite the fabric was responsible for differences amounting to 15 per cent. of the average crushing strength of the rock according to the orientation of the fabric planes to the directions of pressure employed when the granite was crushed.

The latest and most valuable works dealing with the failure of materials composed of non-isotropic elements are those of Brandtzaeg (3) and Rŏs (7). Both of them, however, failed to take into account the non-isotropy of the bodies as a whole.

As yet, no experiments have been made with plastic deforma-

SOLUTION, TRANSPORTATION AND PRECIPITATION OF MANGANESE.

W. S. SAVAGE.

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INTRODUCTION.

MANGANESE and manganiferous ore deposits are largely of secondary origin, that is to say, they are concentrated from manganese minerals more sparsely distributed in rocks.[1] The deposits may be sedimentary, residual, replacement, or bog manganese deposits, and thus there is a close similarity between the types of ores of iron and those of manganese. The gossan iron ores are the one exception. Manganese sulphides are not common and their oxidation products are rarely found. The manganese minerals found in secondary concentrations are numerous but oxides, hydroxides and carbonates predominate.

Manganese was first recognized as a constituent of ground water in 1896.[2] In the year 1906 a serious condition ascribed to iron and manganese occurred suddenly in the water supply of Breslau, Germany, which demanded prompt attention, and bacteriological and chemical methods for their removal were studied. Since that time the problem of demanganization of municipal

[1] Ries, H.: Economic Geology, p. 760. John Wiley & Sons, New York, 1925.

[2] Zapffe, Carl: Elimination of Manganese from Ground Waters. Minnesota Municipalities, vol. XIV, no. 9, p. 403, 1929.

water supplies, both in Europe and on this continent, has assumed the magnitude of a serious economic problem. For this reason, the study of the solution, transportation, and precipitation of manganese has a very practical value apart from the more fundamental question of the origin of secondary manganese deposits.

ACKNOWLEDGMENTS.

The writer takes pleasure in acknowledging his indebtedness to Dr. E. S. Moore, Professor of Economic Geology in the University of Toronto, for the supervision and co-operation which have made this work possible. Thanks are due to Professor L. J. Rogers of the Department of Chemistry for many helpful suggestions bearing upon the chemical side of the investigation, and to Professor A. MacLean of the Department of Geology for constructive criticism. The writer feels particularly indebted to Mr. Carl Zapffe of Brainerd, Minnesota, who has contributed much valuable information. For collecting and forwarding samples of water from the vicinity of manganese deposits the writer wishes to express his appreciation to Dr. W. J. Wright, Provincial Geologist of New Brunswick.

MANGANESE IN NATURAL WATERS.

Springs and underground waters in general contain much more manganese than surface waters. Twenhofel [3] states that the manganese content of underground or spring waters varies from a trace to 117.0 parts per million: commonly it ranges from 0.5 to 5.0 parts per million.

Until recently, on this continent, very little attention has been paid to manganese in natural waters. It may even be said that it is general practice not to analyze water for its manganese content.

Clarke [4] gives an exhaustive series of analyses of the river waters of North and South America. These lists have been com-

[3] Twenhofel, W. H.: Treatise on Sedimentation, pp. 406–407. Williams & Wilkins, Baltimore, Md., 1926.

[4] Clarke, F. W.: The Data of Geochemistry. U. S. Geol. Surv. Bull. 770, p. 63, 1924.

piled from thousands of analyses, yet in only two instances has manganese been recorded in the analyses, and then only when present in excess of one part per thousand.

Several investigators [5] have shown that the presence of 0.5 part per million and less of manganese in the water used for technical purposes is a source of serious trouble. Between the limits of one part per thousand of manganese content, which appears to be the smallest quantity taken into consideration in the general run of analyses, and one part in two million of manganese content, which is more than sufficient to be troublesome, there is a wide and almost virgin field for investigation. The scattered analyses that are available suggest that manganese in solution in natural waters is much more general than hitherto suspected.

SOLUTION OF MANGANESE.

The solution of manganese from the rocks by percolating meteoric waters appears to be generally accepted. A review of the literature indicates, however, that there is a considerable diversity of opinion concerning the chemical factors involved.

Acid waters, containing free sulphuric or hydrochloric acid, such as are found in volcanic regions, or which obtain their acidity from the oxidation of sulphides, have a strong solvent action on the surrounding rocks. Clarke [6] states that such acid waters are, however, relatively rare, and their geological importance as solvents is small compared with that of carbonated waters. He considers meteoric waters carrying free carbonic acid to be the most powerful agents in the solution of rocks.

Deposits of manganese carbonate are readily attacked by acid waters, and in the case of surface waters carrying free carbonic acid, the manganese will again be taken into solution and transported as the bicarbonate. The figures quoted by Vincent [7] for

[5] Zapffe, Carl: Deposition of Manganese. ECON. GEOL., vol. 26, p. 799, 1931. Applebaum, S. B.: Manganese in Ground Water and its Removal. Jour. Ind. and Eng. Chem., vol. 8, p. 160, 1916.

[6] Clarke, F. W.: *Op. cit.*, p. 210.

[7] Vincent, V.: Compte. Rendu. 162, pp. 259–269, 1916.

the solubility of the higher oxides of manganese by carbonated waters show that the quantity taken into solution is actually less than can be obtained by the action of carbonated waters on rocks containing small quantities of manganese in primary distribution. The relative insolubility of the higher oxides thus explains why the successive solution and redeposition of manganese oxides does not lead to the production of a zone of secondary enrichment as in the case of copper and silver deposits.

Twenhofel [8] points out that solution, oxidation, hydration, and carbonation are the processes responsible for the greater portion of rock decay. Solutions from decaying organic matter are thought to play an important part in rock decomposition, but the extent of their influence has yet to be established.

A series of experiments were performed by the writer to determine the solvent action of pure water, oxygenated water, carbonated water, and solutions from decaying organic matter on the manganese content of certain rocks known to contain that element in small amount.

A syenite from Port Coldwell, Ontario, and a diabase from Sudbury, Ontario, were the rocks used in the solution experiments. Analyses showed the syenite to contain 0.062 per cent. MnO, and the diabase 0.136 per cent. MnO. Coarsely and finely ground samples of each rock were treated in order to determine whether the degree of disintegration was a factor in the rate of solution.

A specimen of the syenite was ground to 65-mesh and 100 grams were placed in each of four winchesters with two litres of distilled water. One bottle containing only the powdered sample and distilled water was set aside. Carbon dioxide was bubbled through the second bottle, and oxygen passed through the third, in each case for 24 hours. One hundred grams of earthy peat obtained from the bog at Holland Landing, Ontario, which had been permitted to dry for six weeks at room temperature, was added to the fourth bottle.

Similar series of four bottles each were prepared, using 200-

[8] Twenhofel, W. H., *Op. cit.*, p. 11.

mesh syenite, 65-mesh diabase and 200-mesh diabase powders. In order to determine the quantity of manganese which might be taken into solution from the container or the earthy peat, four additional winchesters were prepared as "blanks." These bottles contained respectively, two litres of distilled water, two litres of carbonated water, two litres of oxygenated water, and two litres of distilled water to which was added 100 grams of the earthy peat. All twenty bottles were sealed with paraffin wax and permitted to stand undisturbed for 286 days.

At the end of the elapsed time, 500 c.c. of solution was drawn off from each winchester and analysed for manganese content by the colorimetric method.[9]

The carbonated and oxygenated solutions were retreated with carbon dioxide and oxygen for 24 hours and, together with the other solutions, were set aside again for an additional 70 days. During this period each bottle was shaken up at bi-weekly intervals in order to simulate conditions of circulating waters. At the end of the time the solutions were analysed again for their manganese content.

A study of the results listed in Table I shows that in every case, after 286 days at rest, more manganese was taken into solution from the 65-mesh rock than from the 200-mesh rock. The fine-mesh powder evidently settled as a dense compact mass on the bottom of the winchester and permitted less circulation of the solutions than in the case of the coarser powder. This explanation is borne out by the fact that during a further 70 days with bi-weekly agitation, the rate of solution in general was greatest from the 200-mesh powders. Oxygen in solution appeared to decrease considerably the ability of water to dissolve manganese from syenite and diabase, and the oxygenated solutions did not conform to the above rule. The other exception was in the case of the diabase powders in carbonated water.

Carbonated water was found to be the outstanding solvent of manganese from rocks containing manganese-bearing silicates.

[9] Washington, H. S.: Manual of the Chemical Analysis of Rocks, p. 220. John Wiley and Sons, New York, 1919.

TABLE I

SOLUTION OF MANGANESE FROM SYENITE AND DIABASE.
(Parts per million.)

Rock	Mesh	Solutions							
		Distilled water		Carbonated water		Oxygenated water		Distilled water and peat	
		Time in contact with rock		Time in contact with rock		Time in contact with rock		Time in contact with rock	
		286 days at rest	70 extra days with agitation	286 days at rest	70 extra days with agitation	286 days at rest	70 extra days with agitation	286 days at rest	70 extra days with agitation
		MnO	MnO	MnO	MnO	MnO	MnO	MnO	MnO
Blank		Trace	Trace	Trace	Trace	Trace	Trace	4.40	4.00
Syenite	65	0.18	0.26	7.00	12.80	Trace	0.03	5.94	4.62
Syenite	200	0.16	0.44	3.20	9.54	Trace	0.02	5.70	6.40
Diabase	65	0.48	1.28	0.36	1.40	0.05	0.22	5.24	4.26
Diabase	200	0.42	2.24	0.30	0.84	0.02	0.10	4.60	6.20

Trace = less than 0.02 part per million.

At first glance this does not appear to be true in the case of the powdered diabase. Manganous oxide to the extent of 7.00 parts per million was taken into solution from 65-mesh syenite in contact with carbonated water for 286 days, whereas only 0.36 parts per million MnO was dissolved from 65-mesh diabase under the same conditions. The explanation, however, is to be found in the fact that the diabase contained a considerable amount of disseminated iron sulphide which yields readily to the action of carbonic acid. At the end of the 286-day period a 100 c.c. sample of solution was taken from the bottle containing 200-mesh diabase with carbonated water and exposed to the air for three days. A yellowish brown flocculent precipitate of iron hydroxide resulted. The greater part of the carbon dioxide in the solution, therefore, reacted with the more easily attacked iron sulphides, and was not available to act on the manganese minerals present in the diabase powder. There is no reason to doubt that in the absence of the sulphides, or in the presence of abundant carbon dioxide, manganese would be as readily taken into solution from diabase as from syenite.

During the 70 days with agitation the carbon dioxide reacted to a relatively greater extent with the sulphides in the more finely ground diabase. This fact explains why the diabase in carbonated water was one of the exceptions to the rule that during the period of agitation the rate of solution of manganese was greatest from the rocks ground to 200-mesh.

Peat solution ranks next to carbonated water as an effective solvent of manganese. Since the products of vegetable decay are complex and depend on so many variable factors, there is considerable difference of opinion regarding the importance of the part they play in rock decomposition. When plants decay, organic acids are liberated, and Bolton [10] has shown that isolated organic acids, especially citric acid, have a strong solvent action on minerals. The so-called "humus acids" were formerly considered to be very important, but Clarke [11] states that their alleged activity as agents in rock decomposition is most questionable. These substances proved to be not true acids, but vague mixtures of colloids which yield carbonic acid on oxidation, and whose precise chemical nature has yet to be determined. Endell [12] proved that the acidity of swamp water is chiefly that of carbonic acid resulting from the decay of vegetable matter under oxidizing conditions.

The peat solutions were not regenerated at the beginning of the 70-day period, as were the carbonated and oxygenated solutions. The opening of the winchesters containing the peat solutions at the end of the 286-day period and the consequent admittance of air evidently resulted in a slight precipitation of manganese. In general, this loss of manganese was not overcome by further solution during the 70-day period, but the solutions from the 200-mesh powders showed an increase in manganese content due to the greater degree of solubility of the finer grained powders when an adequate circulation was provided.

Conclusions.—1. Manganese in primary distribution in rocks

[10] Bolton, H. C.: Annals New York Acad. Sci., vol. I, 1877, p. 1, and vol. II, 1880, p. 1.

[11] Clarke, F. W.: *Op. cit.*, p. 487.

[12] Endell, K., Neues Jahrb. Beil. Bd. 31, 1910, p. 1. Jour. prakt. Chemie. 2nd. ser., vol. 82, p. 414, 1910.

is taken into solution chiefly by the action of percolating carbonated waters.

2. Carbonated waters will take manganese carbonate and manganous oxides into solution but the higher oxides of manganese are soluble only to a very slight degree.

3. Peat solution is the next most effective solvent, largely on account of the free carbonic acid resulting from the decay of organic matter. The organic acids may play a small part as solvents of manganese.

4. Distilled water is a poor solvent of manganese but has a relatively greater solvent action on diabase than on syenite.

5. Oxygenated water had the least solvent action of any of the solutions used in the experiments, but was proportionately more effective on the diabase.

6. Fine grinding increased the solvent action of the solutions when circulation was maintained by bi-weekly agitation. The degree of disintegration of a rock has therefore a direct bearing on the quantity of manganese taken into solution by circulating waters.

7. Waters containing free sulphuric or hydrochloric acid may dissolve considerable manganese and play an important part in the secondary enrichment of gold deposits. Such waters, however, are relatively uncommon and their rôle in the solution of manganese is small in comparison with the widespread solvent action of meteoric waters containing free carbonic acid.

TRANSPORTATION OF MANGANESE.

It is generally conceded that manganese is taken into solution during the weathering of rocks containing manganese minerals, and is transported in solution or suspension to be later precipitated, sometimes in sufficient concentration to form secondary manganese deposits of economic importance. Very little is to be found in the literature concerning the mode of transportation.

Dale [13] and Hanson [14] are of the opinion that the transportation

[13] Dale, N. C.: The Cambrian Manganese Deposits of Conception and Trinity Bays, Newfoundland. Amer. Phil. Soc., vol. LIV, pp. 371–456, 1915.

[14] Hanson, G.: *Op. cit.*, p. 11.

of manganese takes place chiefly as the bicarbonate and to a less extent as suspended particles of oxides. Zapffe [15] considers the manganese in solution in the water supply of the city of Brainerd to be carried as the bicarbonate, and on that basis designed a filtering plant which satisfactorily removes the manganese and iron.

In the spring waters at Wiesbaden, Fresenius [16] found that manganese remained in solution much longer than iron when both were present as bicarbonates. Gruner [17] discovered that iron bicarbonate solutions formed by the action of carbonic acid on minerals and rocks, when exposed to the air, precipitated all the iron in three days. Numerous investigators have recognized directly or indirectly that a slight degree of alkalinity is necessary before simple aeration can become a factor in the precipitation of manganese from a bicarbonate solution.

The following reactions for iron and manganese bicarbonates were determined by Tillmans [18] in 1914:

$$(1)\quad 2Fe(HCO_3)_2 + O + H_2O = 2Fe(OH)_3 + 4CO_2$$
$$(2)\quad Mn(HCO_3)_2 + 2H_2O \quad = Mn(OH)_2 + 2H_2CO_3.$$

The reaction for iron takes place in both alkaline and weakly acid solutions. Ferric hydroxide [$Fe(OH)_3$] is a stable compound and is precipitated rapidly from a bicarbonate solution by simple aeration.

The writer performed an experiment in which oxygen and carbon dioxide were bubbled simultaneously through a manganese bicarbonate solution for five days. The solution contained 6.4 p.p.m. of manganese, calculated as MnO. At the end of the five days an analysis showed that none of the manganese had been precipitated.

[15] Zapffe, Carl: Catalysis and its Bearing on the Origin of Lake Superior Iron-bearing Formation. ECON. GEOL., vol. 28, p. 751, 1933.

[16] Fresenius, C. R., Cited by G. Bischof. Lehrbuch der chemischen und physikalischen Geologie: 2nd. ed., vol. I, p. 540.

[17] Gruner, J. W.: ECON. GEOL., vol. 17, p. 436, 1922.

[18] Tillmans, J. von.: Ueber die Entmangung von Trinkwasser. Jour. Gasbel. u. Wasser., vol. 57, p. 713, 1914.

Manganese, therefore, will remain in solution as bicarbonate and the above reaction will not take place until conditions have been encountered which give the solution a slight degree of alkalinity. The attainment of a slight degree of alkalinity by the solution is indicative that the excess of carbon dioxide has been removed. Under these circumstances the unstable manganous hydroxide [$Mn(OH)_2$] can form and remain in solution, but the reaction is reversible and nothing results until some controlling factor enters into the reaction.

A solution containing manganese bicarbonate, resulting from the contact of carbonated water with powdered syenite in a sealed winchester for a period of one year, was found by the writer to have a pH of 6.6. After exposure to the atmosphere for seven days the pH had changed to 7.1. An analysis showed that the solution contained 4.50 p.p.m. of manganese, calculated as MnO. Since the pH indicated that the necessary condition of slight alkalinity had been attained, the manganese remaining in solution was considered to be present as bicarbonate and manganous hydroxide in a state of unstable equilibrium.

Oxygen was bubbled through 100 c.c. of the solution for three days, and at the end of that time a slight precipitate could be observed. An analysis showed that only a trace of manganese remained in solution.

Zapffe [19] has shown that under oxidizing conditions, when precipitation of manganese has been initiated from aqueous solution, the catalytic action of the precipitate accelerates the process and insures a very complete removal of the manganese.

Analyses made by the writer of the four samples of surface water from the manganese deposits at North Renous and Upper Blackville, New Brunswick, provided by Dr. W. J. Wright, Provincial Geologist, showed that in each case less than 0.02 p.p.m. of manganese remained in solution.

The work of Bradley, quoted by Zapffe,[20] shows that the oxidation of manganous hydroxide results in the formation of a stable,

[19] Zapffe, Carl: Deposition of Manganese. *Op. cit.*
[20] *Idem*, p. 821.

though partly dehydrated manganese hydrate (MnO.OH). According to Tillmans [21] the oxygen of the water forms manganese dioxide (MnO_2) from the hydrate.

It follows, therefore, that when a slightly alkaline solution containing manganese bicarbonate and manganous hydroxide in a state of unstable equilibrium meets with the oxidizing conditions such as exist in the surficial layers of bodies of water and in water-falls and rapids, the manganous hydroxide can be oxidized and precipitated as a partly dehydrated manganic hydrate, which in turn is oxidized to manganese dioxide. The carbon dioxide can escape, and if the oxidizing conditions are maintained, the reaction will go to the right until all the manganese has been precipitated. The following equations may illustrate what takes place:

$$2\,Mn(HCO_3)_2 + 4H_2O = 2\,Mn(OH)_2 + 4H_2O + 4CO_2$$
$$2\,Mn(OH)_2 + 4H_2O + O = 2\,MnO.OH + 5H_2O$$
$$2\,MnO.OH + 5H_2O + O = 2\,MnO_2 + 6H_2O.$$

The possibility that the precipitation of manganese under the above circumstances might be prevented by the presence of organic matter in surface waters was suggested by the results obtained by Moore and Maynard [22] for iron. A series of experiments were conducted by the writer in which peat solutions of known organic content were added in varying proportions to solutions containing manganese dissolved from powdered syenite by carbonated waters. Oxygen was bubbled through the resulting mixtures for four days and analyses made to determine the quantity of manganese remaining in solution.

Two peat solutions were used in the experiments. The first solution was prepared by adding distilled water to a sample of peat from Holland Landing, Ontario, which had been permitted to dry in air for six weeks. The second solution was obtained from a mixture of bog water and decayed vegetable matter taken from another part of the marsh at Holland Landing. In each

[21] Tillmans, J. von. Cited by Zapffe, *Idem*, p. 822.

[22] Moore, E. S. and Maynard, J. E.: Solution, Transportation, and Precipitation of Iron and Silica. ECON. GEOL., vol. 24, Nos. 1, 2, 3, 1929.

case the mixture was boiled, filtered, and the resulting solution analysed for organic content.

A sample of each of the peat solutions was dialysed for ten days. At the end of that time analyses showed that only a trace of organic matter remained in the solution, but a surface film of gelatinous precipitate had formed inside the parchment cup in each case. This gelatinous precipitate showed a high organic content and attested to the presence of organic colloids in the original peat solutions.

The results of the oxidation experiments are listed in Table II.

TABLE II.
OXIDATION EXPERIMENTS ON MIXTURES OF MANGANESE BICARBONATE SOLUTION AND PEAT SOLUTION.

Mixtures of manganese bicarbonate solution and peat solution			Manganese remaining in solution after oxygenation for four days (p.p.m. MnO)
Manganese in the mixture (p.p.m. MnO)	Peat solution No.	Organic carbon in the mixture (p.p.m.)	
4.0 p.p.m.	1	292 p.p.m.	0.15 p.p.m.
8.2	1	97	0.26
6.6	2	32	0.16
8.1	2	16	0.18
8.8	2	8	0.19
9.6	None	None	0.28

In each case the free carbonic acid in the solution had to be removed by the escape of carbon dioxide before precipitation could be initiated. In an experiment previously described where a manganese bicarbonate solution, already slightly alkaline, was oxygenated, only a trace of manganese remained in solution after three days.

The above results indicate that when manganese bicarbonate solutions mingle with waters of high organic content under oxidizing conditions, the organic matter does not stabilize the manganese in solution and permit further transportation, as Moore and Maynard [23] found it does in the case of iron.

Conclusions.—1. Manganese is transported chiefly as the bi-

[23] Moore, E. S., and Maynard, J. E., *Op. cit.*

carbonate in acid waters which as a rule owe their acidity to the presence of free carbonic acid.

2. When such waters, by the loss of carbon dioxide, become neutral or slightly alkaline, the manganese bicarbonate molecule can split up and the unstable manganous hydroxide will form and remain in solution. Further transportation can then take place, with the manganese in solution as manganese bicarbonate and manganous hydroxide in unstable equilibrium, until the necessary conditions are encountered which result in precipitation.

3. The transportation of manganese under these conditions appears to be independent of the presence of organic matter in the water, but a relatively small quantity of manganese may be carried as salts of organic acids.

PRECIPITATION OF MANGANESE.

A review of the literature on the subject of the precipitation of manganese indicates that a preponderant number of the investigators were primarily interested in the practical problem of manganese removal from municipal water supplies.

On this continent Zapffe [24] has made a thorough study of the problem of demanganization of water supplies, and considerable information which he made available has been of assistance in the preparation of this paper.

At the end of the last century the interest in processes for the deposition of iron and manganese was chiefly centered on bacteriological methods. Six species of thread bacteria have been identified, which when first found were associated with iron oxides and became known as "iron bacteria." It is now known that at least two of these species, *Crenothrix polyspora* and *Leptothrix ochracea,* increase in size on inorganic manganese salts and attack them in preference to iron salts.

Thread bacteria are abundantly present in soils which are subject to erosion by surface waters carrying manganese in solution as bicarbonate. They have also been found with deposits of

[24] Zapffe, Carl: *Op. cit.,* Minnesota Municipalities, vol. 14, no. 9, 1929. ECON. GEOL., vol. 26, no. 8, 1931; vol. 28, no. 8, 1933.

manganese oxides in the mains of municipal water supply systems, and undoubtedly play a considerable part in the precipitation of manganese.

A still more important factor in the precipitation of manganese from a bicarbonate solution is the catalytic action of manganese dioxide. Zapffe [25] has shown that when precipitation has been initiated, the deposited manganese dioxide exerts a cumulative catalytic action which is the preponderant factor in the removal of the manganese from the solution.

It has already been shown that a bicarbonate solution of manganese must become slightly alkaline before the bicarbonate molecule will split up and precipitation can take place. In the experiments previously described, the free carbonic acid in the solution was removed by the escape of carbon dioxide to the atmosphere.

The necessary alkalinity can also be attained if the bicarbonate solution of manganese flows over a limestone bed.

Four grams of powdered calcium carbonate were added to 100 c.c. of a bicarbonate solution of manganese containing 8.4 p.p.m. of manganese calculated as MnO. The mixture was shaken up and permitted to settle. The clear liquid was filtered off and the residue washed on to the filter paper. An analysis showed that only 0.6 p.p.m. MnO remained in solution. The manganese could not have been precipitated as an oxide since the precipitation took place almost immediately, and if manganous hydroxide had formed it would have remained in solution. It would appear therefore, that the manganese was precipitated as manganese carbonate. This conclusion was confirmed by pouring dilute hydrochloric acid over the residue on the filter paper. An effervescence of carbon dioxide took place and the residue was entirely dissolved, showing that the precipitate consisted of carbonates of calcium and manganese.

Manganese bicarbonate, in the presence of calcium carbonate, releases the carbonic acid molecule which dissolves some of the calcium carbonate to form calcium bicarbonate, and a precipitation

[25] Zapffe, Carl: *Op. cit.*, Deposition of Manganese, pp. 817, 824.

of manganese carbonate takes place. The reaction may be illustrated by the following equation:

$$Mn(HCO_3)_2 + CaCO_3 = Ca(HCO_3)_2 + MnCO_3.$$

The above experiment provides a simple explanation of the intimate association of bedded manganese deposits of the carbonate type with limestones.

Twenhofel [26] states that there is no good record of the precipitation of manganese carbonate from surface waters, either marine or non-marine, except by replacement of a pre-existing rock, generally a carbonate.

Conclusions.—1. A bicarbonate solution of manganese must become neutral or slightly alkaline before precipitation can take place. Aeration, the presence of calcium carbonate, or the alkaline reaction of thread bacteria, may be independent or cooperative agents in bringing about this condition.

2. When the free carbonic acid has been removed from a manganese bicarbonate solution, the bicarbonate molecule can split up, and the unstable manganous hydroxide [$Mn(OH)_2$] can form and remain in solution.

3. Where oxygen is available, the unstable manganous hydroxide may be oxidized and precipitated as a partly dehydrated manganic hydrate (MnO.OH) which in turn is readily oxidized to manganese dioxide (MnO_2). The precipitation may be materially assisted by certain species of thread bacteria which are known to precipitate MnO_2 under oxidizing conditions. The deposited MnO_2 has a strong catalytic action which accelerates the change of manganese bicarbonate into manganous hydroxide and carbon dioxide, and finally insures the complete precipitation of the manganese from the solution.

4. Manganese may be deposited as a carbonate when a bicarbonate solution of manganese flows over a limestone bed. If any free carbonic acid remains in the solution, it will combine with calcium carbonate to form soluble calcium bicarbonate. A reaction takes place between the manganese bicarbonate solution

[26] Twenhofel, W. H.: *Op. cit.*, p. 407.

and the calcium carbonate, resulting in an exchange of the carbonic acid molecule. Additional calcium will be taken into solution as the bicarbonate, and manganese carbonate will be precipitated.

CONCLUSIONS REGARDING THE ORIGIN OF MANGANESE DEPOSITS.

Secondary manganese deposits originate directly or indirectly by the precipitation and concentration of manganese extracted by percolating waters from manganese-bearing silicates present in igneous rocks. Carbonated water is the chief agent in the solution of manganese. Peat solution, mainly on account of the carbonic acid resulting from plant decay, is also an effective solvent.

Deposits of manganese carbonate may be taken into solution again by the same agencies and reprecipitated elsewhere as carbonate or oxide, but the higher oxides of manganese are relatively insoluble in surface waters.

The manganese is transported as bicarbonate until such time as the solution becomes slightly alkaline. The attainment of this state indicates that any free carbonic acid in the solution has been removed. Numerous factors may be operative in bringing about this condition. Exposure to the atmosphere in surface waters over a period of time, or aeration in water-falls and rapids, will result in the loss of the free carbonic acid, or it may react with calcium carbonate to form calcium bicarbonate in the presence of limestone. Thread bacteria are abundant in the soil, which is subject to erosion by surface waters, and these bacteria constitute another factor in neutralizing the free carbonic acid, since they are known to have an alkaline reaction.

When a bicarbonate solution of manganese has become slightly alkaline, the unstable manganous hydroxide [$Mn(OH)_2$] can form and remain in solution. Under these circumstances, the manganese may be considered to exist in the solution as manganese bicarbonate and manganous hydroxide in a state of unstable equilibrium.

Manganese in solution as manganous hydroxide may be oxidized and precipitated as a partly dehydrated manganic hydrate

(MnO.OH), which in turn readily oxidizes to manganese dioxide (MnO_2), when oxidizing conditions are encountered such as exist in the surficial layers of bodies of water and in water-falls and rapids. *Crenothrix polyspora, Leptothrix ochracea,* and certain other species of thread bacteria, if present, may aid materially in the extraction of the manganese from solution, since under oxidizing conditions they are known to precipitate manganese dioxide. If the oxidizing conditions are maintained, the reaction will continue until all the manganese has been precipitated. The cumulative catalytic action of the deposited manganese dioxide, which accelerates the conversion of manganese bicarbonate to manganous hydroxide and carbon dioxide, will quickly bring about the complete precipitation of manganese from the solution.

Organic matter in the water does not appear to stabilize the manganese in solution or to prevent precipitation under the above conditions, as it does in the case of iron.

The characteristic oölitic and concretionary nature of manganese deposits has given rise to considerable speculation. The recent work of a number of investigators on the problem of the origin of oölites has established that organisms of low rank such as algæ and bacteria have been intimately associated with the formation of some oölitic deposits. It may be inferred in view of this conclusion that the manganese-depositing bacteria are capable of precipitating manganese dioxide in such manner as to form oölitic or concretionary deposits. The catalytic action of manganese dioxide may also be a factor. The tests conducted at Brainerd by Zapffe [27] indicate in a convincing manner how a minute grain of any substance becoming coated with manganese dioxide can become the nucleus of concretions and foster their growth.

When a manganese bicarbonate solution comes in contact with a limestone deposit, any free carbonic acid remaining in the solution reacts with calcium carbonate to form calcium bicarbonate which goes into solution. A reaction takes place between the manganese bicarbonate in solution and the calcium carbonate of

[27] Zapffe, Carl: Deposition of Manganese, *Op. cit.*, p. 829.

the deposit in which an exchange of the carbonic acid molecule is effected. Calcium carbonate goes into solution as the bicarbonate and is replaced by a deposition of manganese carbonate.

Linck [28] has shown that calcareous oölites form in the sea as direct chemical precipitates, and it is possible that oölitic manganese carbonates may form in the same way. It is well known, however, that certain oölitic deposits undoubtedly obtained their present mineral composition by replacement processes. Since manganese carbonate deposits replace pre-existing calcium carbonate deposits, it is conceivable that the oölitic and concretionary nature of manganese carbonate deposits may result, in certain cases, from the direct replacement of oölitic and concretionary calcium carbonate.

Shallow seas in the proximity of former shorelines provided the most favorable environmental conditions for the accumulation of manganese in deposits of the sedimentary oxide and carbonate types. The chemical state in which the manganese reached the sea would depend on the distance of transportation and the conditions encountered on the way.

Manganese taken into solution from rocks undergoing disintegration near the sea coast might reach the sea in solution as manganese bicarbonate and manganous hydroxide in unstable equilibrium. From the oxygenated near-shore surface waters manganese oxides would be precipitated in intimate association with sands and muds which later would be consolidated into sandstones and shales. A manganese bicarbonate solution might be carried into deeper water before losing its free carbonic acid and there encounter deposits of calcium carbonate. A deposition of manganese carbonate would take place by replacement of some of the calcium carbonate, and after consolidation the manganese carbonate deposits would be found associated with limestones.

On the other hand, if the rocks from which the manganese was dissolved were distant from the sea coast, conditions might be encountered during transportation which would bring about precipitation. The combined agencies of aeration, catalysis, and the

[28] Linck, G.: Neues Jahrb. Min. Geol. u. Pal., B. B. XVI, pp. 495–513, 1903.

influence of bacteria would cause the deposition of manganese oxides. Such deposits are forming today near springs, and in wells, bogs, lakes, and rivers. Twenhofel [29] points out that flocculent manganese oxides, as fine sediment, are probably delivered to the ocean by all river waters. On reaching the sea the suspended manganese oxides would be deposited near the shore in the same association as the manganese oxides deposited from solution.

Manganese deposits are widely distributed throughout the world, and on this continent they are found in rocks of nearly all geological ages. The majority of these deposits, however, are small or not sufficiently concentrated to be of economic importance. A combination of favorable environmental conditions must have existed at certain times to bring about the formation of large deposits of commercial grade. Hanson [30] stresses the importance of deep rock decay as a necessary condition for the formation of extensive manganese deposits. In tropical countries where rock decay takes place faster than the removal of the decayed matter by erosion, conditions are favorable for the solution of manganese by circulating waters which percolate through the deeply weathered material. Hanson points out also that manganese deposits are often absent from large areas in various parts of the earth where the rocks carry an average content of manganese, and, on the other hand, generally occur where the rocks contain a more than usual amount of manganese-bearing minerals. According to Harder [31] and Fermor,[32] source rocks with a manganese content above normal, together with conditions favoring deep rock decay, were the important factors contributing to the formation of the extensive manganese ore deposits of Brazil and India.

In the United States, the manganese deposits of the Ap-

[29] Twenhofel, W. H.: *Op. cit.*, p. 407.

[30] Hanson, G.: *Op. cit.*, p. 20.

[31] Harder, E. C.: Manganese Ores in Russia, India, Brazil, and Chile. Trans. Amer. Inst. Min. Eng., vol. 56, 1917.

[32] Fermor, L. L.: Manganese Ore Deposits of India. Mem. Geol. Surv. of India, vol. 37, 1909.

palachian region are the most important. The pre-Cambrian rocks of the Piedmont region are considered to be the source of the Paleozoic sediments and the manganese deposits. These pre-Cambrian rocks are known to contain a more than average amount of manganese-bearing minerals. Throughout the Canadian Shield, as far as is known, the pre-Cambrian rocks have only an average content of manganese, but there can be little doubt that the weathering of these rocks for geological ages before the Pleistocene must have given rise to surficial concentrations of manganese. Such deposits, however, would be completely worn away and scattered during the continent-wide glaciation which occurred in Pleistocene time, and today manganese deposits are lacking over the greater part of Canada.

The solution, transportation, and precipitation of manganese are a sequence of simple natural processes which must have operated in all geological ages, and are taking place today wherever manganese occurs in the rocks, carbon dioxide and water are available to take the manganese into solution, and the conditions outlined above are encountered which result in transportation and subsequent precipitation.

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THE GENESIS OF THE TRI–STATE ZINC AND LEAD ORES.

JOHN RIDGE.

INTRODUCTION.

THIS paper deals with the petrography of the jasperoid, the mineral paragenesis, and certain considerations bearing on the origin of the ores. Some 108 specimens, representing many different parts of the area, were examined; these were collected by Professor E. S. Bastin, Mr. John Svatik, and the writer. Through the courtesy of Mr. J. H. Meyers, City Commissioner of Joplin, Missouri, the writer was also able to study the specimens in the Tri-State Mineral Museum.

The specimens were examined under binocular and reflecting microscopes and the evidence so obtained was used in testing the hypotheses offered as to ore deposition. The supervision of Professor Bastin has been invaluable throughout the study. Professor C. H. Behre, Jr., has kindly read and criticised the paper.

THE JASPEROID.

Composition and Color.—The jasperoid is composed of xenomorphic crystals of quartz, only distinguishable under the microscope, and dark brown dots and clusters of organic material between the quartz crystals or rarely included in them. The diameters of the quartz crystals vary from those invisible up to one millimeter. Apparently this organic material was derived from bituminous matter associated with the Boone formation prior to mineralization. To test the organic nature of the material, a thin section of the jasperoid was boiled in dilute hydrochloric acid to remove the intergrown sulphides. This treatment caused no diminution in the amount of dark coloring matter. An analysis of the jasperoid by Mr. George H. Otto showed con-

siderable organic matter in the material, confirming the analysis of Steiger.[1] Since there is nothing else recognizable that could give the color after the sulphides had been removed, the dark brown coloring must be due to organic matter.

Development of the Jasperoid-Cemented Breccias.—Hand specimens showed the following stages of change in the production of the jasperoid-cemented breccias from the Boone limestone:[2] (1) the Boone formation was subjected to tectonic fracturing of the chert, with emplacement of the limestone between the chert fragments; (2) replacement of limestone to a varying extent by dolomite;[3] (3) replacement of this dolomitic limestone largely by jasperoid; (4) partial replacement of the jasperoid by a second generation of dolomite, perfect crystals being formed in the vugs; these cap and intergrow with the tiny dark quartz crystals which grade into the jasperoid, and were formed when silica was deposited in the vugs in the breccias; (5) introduction of the sulphides which intergrew with and capped this younger dolomite.

Evidences for the Replacement Origin of the Jasperoid.—The following points suggest replacement origin for the jasperoid: (1) matrices of the breccias grade from limestone, to part limestone and part dolomite, to part dolomitic limestone and part jasperoid, and finally to jasperoid; (2) in thin sections of jasperoid, dolomite crystals are found which show ragged replacement outlines against jasperoid and contain small quartz crystals in their otherwise unattacked centers; (3) many chert fragments have outlines that match those of adjacent fragments; they therefore could not at any time have been deprived of the support of a matrix to hold them in the same relative position;

[1] Van Hise, C. R., and Bain, H. F.: Lead and Zinc Deposits of the Ozark Region. U. S. Geol. Surv., 22nd. Ann. Rept., Pt. II, p. 121, 1902.

[2] Weidmann, Samuel: The Miami-Picher Zinc-Lead District, Oklahoma. Okla. Geol. Surv., Bull. 56, pp. 14 and 61, 1932.

Smith, W. S. T., and Siebenthal, C. E.: The Joplin District. U. S. Geol. Surv., Folio No. 148, pp. 3 and 13, 1907.

[3] Dolomite was tested for in this investigation by the use of Lemberg's solution. (See Fairbanks, E. E.: A Modification of Lemberg's Staining Method. Amer. Miner., vol. 10, pp. 126–127, 1925.)

(4) in some of the jasperoid there are grains of glauconite similar to those found in many parts of the Boone formation, and thus probably residual in the jasperoid after the replacement of limestone.[4]

Origin of Vugs in the Jasperoid.—It has been suggested that the chert in the Boone formation was fractured by slumping due to the solution of limestone associated with it. In the open spaces thus formed the jasperoid was supposed to have deposited as a silica gel which was later dehydrated and crystallized to form the jasperoid, leaving the unfilled portions as vugs. However, this does not agree with the evidence that the jasperoid was formed by the replacement of the dolomitic-limestone matrix. Since it is certain that some of the jasperoid, at least, was formed by replacement, and since all the jasperoid, even in thin section, appears to be much the same, it is reasonable to suppose that, if open-space filling were important in the production of jasperoid, the type of crystallization in such filled spaces should be similar to that produced by replacement of solid rock. However, the examination of hand specimens shows that the silica deposited in vugs crystallized as automorphic quartz; whereas that deposited by replacement of dolomitic limestone assumes the xenomorphic granular texture already mentioned. This appears to furnish a criterion of distinction between silica which replaces dolomitic limestone and that which fills open spaces. From an inspection of the hand specimens, it appears that the filling of open spaces played only a small part in silicification.

From the above, it appears most likely that the vugs in the jasperoid were inherited from the dolomitic limestone. There are two ways in which vugs could have developed before jasperoid mineralization: (1) by an incomplete filling of the spaces between chert fragments at the time the breccia was formed, and (2) by later solution of limestone and dolomitic limestone. These vugs are commonly more round than elongate. In a general way, the larger the percentage of chert in the walls of the vug, the more likely it is that it was formed by incomplete filling.

[4] Tarr, W. A.: Personal communication, March, 1934.

However, there are some narrow, elongate vugs in the dolomitic limestone, apparently formed mainly by solution, and filled with dolomite which is much more coarsely textured than that of the main mass of the dolomitic limestone. Such dolomite is clearly of a later generation than that which has formed part of the matrix, since these elongate vugs, in many cases, run into the larger, more rounded ones where the coarser dolomite crystallized in typical saddle-shaped forms sharply bounded by the dolomite of the walls.

There is another possible way in which vugs might have developed in the jasperoid. If the material had replaced the limestone as a silica gel, it would have undergone later dehydration and crystallization. These processes would have produced shrinkage cracks in the jasperoid unless they took place under pressure. If the gel had been emplaced under sufficient pressure to prevent the formation of shrinkage cracks, the gel would have been forced into the vugs inherited from the dolomitic limestone matrix and would have filled them. Since such vugs still exist, the jasperoid could not have been derived from the dehydration and crystallization of a silica gel under sufficient pressure to prevent the formation of shrinkage cracks.

Therefore it appears that, if the jasperoid were emplaced as a silica gel, it would show cracks which could be definitely related to shrinkage. It seems probable, from their form, that the larger, more rounded vugs were not due to shrinkage, but there remains the possibility that some of the elongate ones were. Even this possibility, however, seems excluded, since in both the rounded vugs (almost certainly inherited from the dolomitic limestone matrix) and the elongate vugs, the sequence and general character of the mineralization is the same; a criterion which, in the absence of better ones for differentiating between cracks formed by shrinkage and elongate vugs formed by solution and inherited from the preceding matrix, seems applicable here. These facts would argue against the jasperoid having been deposited as a silica gel.

PARAGENESIS.

Before the results of the paragenetic studies are presented, it must be emphasized that they are derived from the inspection of a large number of specimens, since complete mineral development in any one specimen is exceptional.

First Stage of Mineralization.—The paragenetic relations of the first minerals of this stage have already been described and may be diagrammed as follows:

The sulphides cap but do not intergrow with the dark quartz. From this it is evident that the sulphides are completely separated from the dark quartz, and probably from the jasperoid, in time of deposition. The presence of the sulphides in ragged, disseminated masses, irregular veinlets, and automorphic crystals in the jasperoid points to their replacement of it.

Pyrite was the first sulphide to form; it replaces both dolomite and jasperoid, and is, in turn, replaced by both sphalerite and galena. Facts that carry evidence for these relations are: (1) pyrite is found in dolomite and jasperoid as automorphic crystals and in veinlets and disseminated masses occupying cracks and cleavage planes; (2) pyrite is cut by ragged veinlets of galena, bearing pyrite inclusions, but there are no galena inclusions in pyrite; (3) there are ragged masses of pyrite in sphalerite but none of sphalerite in pyrite.

There is no evidence of overlap in the time of deposition of pyrite with that of sphalerite and galena. There is, for example, no intercrystallization with crystal boundaries of each mineral showing in the same neighborhood.

Galena and sphalerite show the following inter-relations: (1) dolomite is capped by and intergrown with galena which is partially capped by and intergrown with sphalerite; (2) dolomite is capped by and intergrown with sphalerite which is, in turn, par-

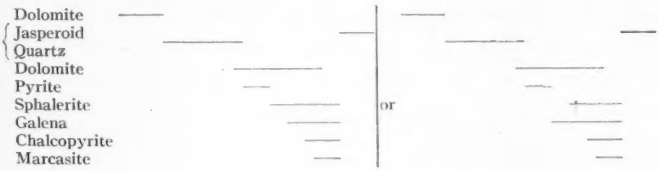
tially capped by and intergrown with galena. Sphalerite began to deposit first more often than galena. In a few cases where galena is absent, sphalerite began to deposit before dolomite, but this is exceptional.

Chalcopyrite is intergrown with and extends beyond sphalerite and galena, and is intergrown with and caps dolomite. In one case, the deposition of chalcopyrite began before that of galena, but here the chalcopyrite was many times as abundant.

Marcasite is intergrown with and extends beyond galena, sphalerite and chalcopyrite; and is intergrown with and caps dolomite. The intergrowth is considerable with chalcopyrite, intermediate with sphalerite, and very slight with galena, indicating overlap in the time of deposition. However, there are no specimens that show any of the four sulphides completely capping one another but, rather, the ones that began to deposit later merely extend beyond the others. In such situations, all the sulphides must have been deposited together for at least part of the time. Whether deposition stopped at the same or different times cannot be determined from an inspection of the hand specimens alone. In the latter part of this paper the writer will present a hypothesis to explain the relations of the four sulphides to each other. This hypothesis specifies that the sulphides stopped precipitating at the same time. The paragenesis diagrams are constructed on this basis.

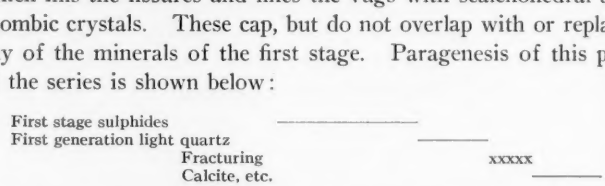
The sulphides are capped by a colorless quartz lighter than that which grades into the jasperoid. Thus, there is demonstrated a hiatus in silica deposition.

The paragenesis established for the first stage of mineralization is given below:



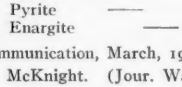
Second Stage of Mineralization.—After the end of the precipitation of the four sulphides and the second generation of silica, there was a definite hiatus in mineral deposition, during which time a fracturing of the minerals of the first generation and of the enclosing rocks occurred. In the fissures and vugs developed were deposited the minerals of the second stage.

The great bulk of the second stage is composed of clear calcite, which fills the fissures and lines the vugs with scalenohedral and rhombic crystals. These cap, but do not overlap with or replace, any of the minerals of the first stage. Paragenesis of this part of the series is shown below:



A second generation of pyrite is also present and forms small cubes capping first-generation sphalerite but not intergrown with it. Where marcasite is also present, its relations differ from those of the second generation of pyrite in that the marcasite not only caps the sphalerite but also is intergrown with it. This suggests that second-generation pyrite is later than first-generation marcasite, although the two are nowhere in contact. According to Tarr, large crystals of calcite are found in the area; these contain concentric rings of pyrite, indicating contemporaneity.[5]

The last event in the second stage of mineralization was the development of simple crystals of enargite.[6] These cap, but are not intergrown with, first-generation sphalerite and marcasite; but cap and are slightly intergrown with calcite. Since the second generation of pyrite is so much more intimately intergrown with calcite than is the enargite, it is probable that enargite deposition began after that of pyrite had ceased. The paragenesis of the second-generation minerals is shown below:



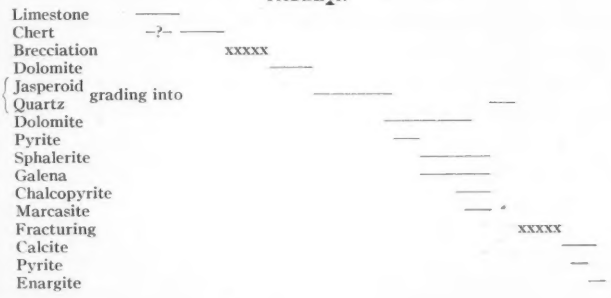
[5] Tarr, W. A.: Personal communication, March, 1934.

[6] First recognized by E. T. McKnight. (Jour. Wash. Acad. Sci., vol. 21, no.15, p. 369, 1931. Econ. Geol., vol. 30, pp. 62–64, 1935.)

With the completion of enargite deposition the end of primary mineralization in the Tri-State area was reached. Secondary changes are beyond the scope of this paper.

Summary.—The following table presents in diagrammatic form a summary of the paragenetic relations described. It should be emphasized that all the evidence for the paragenetic series cannot be given in full in the space available.

TABLE I.



EVALUATION OF OBSERVATIONAL EVIDENCE.

Introduction.—It is obvious that certain lines of evidence are of more value than others in testing the validity of the various hypotheses advanced to account for the origin of the Tri-State ores, just as certain minerals found in an ore body are more diagnostic of the conditions of formation than are others. The following appear to be the more valuable lines of evidence.

All the more acceptable hypotheses brought forward to explain the origin of the Tri-State ores agree on the *epigenetic* origin of the deposits, but there is disagreement as to the source and the physical and chemical character of the mineralizing solutions. It will be recalled that the three leading hypotheses stipulate that the ores were deposited by the agency of (1) descending ground water,[7] (2) ascending artesian solutions,[8] and (3) ascending

[7] Buckley, E. R. and Buehler, H. A.: The Geology of the Granby Area. Missouri Bur. Geol. and Min., vol. 4, 2nd. ser., pp. 80–81 and 87, 1905.

[8] Siebenthal, C. E.: Zinc and Lead Deposits of the Joplin Region. U. S. Geol. Surv., Bull. 606, p. 13, 1915.

thermal solutions of magmatic origin.[9] In the discussion of the observational evidence no mention will be made of the hypothesis involving downward-moving ground water. This omission is intentional, since all the phenomena under consideration are accounted for in practically the same manner by this hypothesis and the artesian one.

Two Stages of Mineralization.—The separation of the mineralization into two distinct stages is the most noticeable fact brought out by the paragenetic studies. Since the minerals developed in the two stages are different, it is logical to suppose that the solutions from which they were deposited were different. This change in the nature of the solutions appears to be related to fracturing.

There is nothing in the mechanism provided by the artesian hypothesis to suggest that fracturing should bring with it a change in the character of the ore-bearing solution. However, supposing that the fracturing during the hiatus in mineral deposition were a fortuitous coincidence, the development of minerals different from those of the first stage is still incompatible with the artesian mechanism. For example, one of the changes was the development of pyrite instead of marcasite. Under the artesian hypothesis, the solutions would in each case have been acid. Although pyrite and marcasite can be deposited side by side at relatively low temperature, a change from the deposition of marcasite alone to that of pyrite alone could, under acid conditions, only be effected by a rise in temperature. This is, of course, not only incompatible with the artesian hypothesis but in diametrical contradiction to it.

On the other hand, the presence of two stages of mineralization becomes a strong argument for the hydrothermal hypothesis. Successive phases of mineralization are a common feature of epithermal deposits,[10] where fracturing or brecciation of the minerals may be followed by the deposition of an entirely new suite of minerals. This may be due to the movement attendant on

[9] Weidmann, Samuel: *Op. cit.*, pp. 77–84.

[10] Lindgren, Waldemar: Mineral Deposits, 3rd. ed., pp. 521–524, 1928.

fracturing, closing old sources of supply and opening the way for either new solutions from other parts of the old source, or for new solutions from a new source.

Thus, the evidence furnished by the two stages of mineralization is seen to favor the hydrothermal hypothesis over the artesian one.

Two Stages of Quartz Deposition.—Within the first stage of mineralization there is a hiatus in quartz deposition. Such a hiatus is more characteristic of hydrothermal than ground-water deposits.

Presence of Enargite.—Enargite was deposited during the second stage of mineralization, showing that the ore-bearing solutions of that stage were igneous in origin. Minerals of the first stage might still have been deposited by the artesian mechanism, but since an igneous source furnished the second-stage solutions, the first-stage solutions might also well have had an igneous source.

Thus the evidence furnished by the presence of enargite favors the hydrothermal over the artesian source for minerals of both stages.

Presence of chalcopyrite.—It is a well known principle that a double salt, such as chalcopyrite, when dissolved in ground water, usually reprecipitates not as a double salt but as single ones. Wells states in this connection that: "The solubilities of the several sulphides, however, differ so greatly that complete separations by fractional precipitation are possible."[11] This would suggest that chalcopyrite did not deposit from an artesian solution. Wells found that hydrogen sulphide added to equal molecular weights of cupric and ferrous ions will not precipitate chalcopyrite.[12] Since this is the mechanism postulated in the artesian hypothesis, and since it does not work under laboratory conditions, doubt is cast on the artesian hypothesis.

Thus the evidence furnished by the presence of chalcopyrite,

[11] Wells, R. C.: The Fractional Precipitation of Some Ore-Forming Compounds at Moderate Temperatures. U. S. Geol. Surv., Bull. 609, pp. 18–20 and 23–24, 1915.

[12] *Idem.*

although not strong, favors the hydrothermal hypothesis over the artesian one.

The Inversion in the Order of Precipitation of Sphalerite and Galena.

According to the artesian hypothesis, lead and zinc ions are carried in solution in balance with bicarbonate ions. The metallic ions were precipitated when the release of pressure made hydrogen sulphide available. The figures quoted by Wells[13] give the solubility product constant (K_{sp}) for galena as 1.5×10^{-12} and that for sphalerite as 43.0×10^{-12}. Hence:

$$\frac{K_{PbS}}{K_{ZnS}} = \frac{1.5 \times 10^{-12}}{43.0 \times 10^{-12}} = 1/30 \text{ (approximately).}$$

In other words, sphalerite will precipitate before galena only in a solution where the ratio of zinc to lead ions is more than 30:1. Moreover, while the two are coming down together, the ratio of the two sulphides in solution and in the resulting deposit will be thirty sphalerite to one galena. However, where sphalerite and galena are found to have precipitated together, the ratio is not more than 3 or 4 sphalerite to one galena. Since the ratio of 30:1 is not even approximated in the deposit during double precipitation, it follows that this mechanism for inverting the order of the beginning of precipitation cannot have been the one that controlled deposition.[14]

An excess of acid in the solution would reduce the concentration of the sulphide ion but this would have no effect on the order of the beginning of precipitation, nor would it cause the omission of any of the sulphides from the sequence.

Colloidal deposition might cause the inversion in the order of the beginning of precipitation. However, there is nothing in the display of perfectly intergrown crystals to suggest this, and there are no textures in the solid rock which suggest it; nor are such textures brought out by etching with aqua regia fumes.

[13] *Op. cit.*

[14] The ratio 30:1 is only an approximation but, since all the other solubilities given by Wells give an even larger ratio, it serves to illustrate the point involved.

It thus appears that the inversion in the order of the beginning of deposition of sphalerite and galena constitutes a serious objection to the artesian hypothesis.

In searching for an explanation of this inversion it is suggested that the ore-bearing solutions, according to the hydrothermal hypothesis, were given off at temperatures much higher than those that they finally reached through cooling. This range of temperature may furnish an explanation for the inversion in the order of the precipitation of sphalerite and galena.

It will be recalled that the paragenetic relations of the four sulphides—galena, sphalerite, chalcopyrite, and marcasite—were such that, although it is possible to say very certainly in what order they began to precipitate, it is impossible to say whether they stopped precipitating at the same or different times. All that can be said regarding the end of precipitation is this: after marcasite began to come down, a considerable amount of chalcopyrite (although less than the amount of marcasite), an intermediate amount of sphalerite, and very little galena precipitated. This can best be explained, in the writer's opinion, by assuming deposition of the four sulphides from a mixed solution by fractional precipitation and at different rates rather than by assuming the longer continuation of supply of some of the sulphides, all depositing at approximately the same rate.

It is possible, from the data furnished by Wells and from the observed behavior of the minerals, to construct a set of solubility curves which will roughly approximate the conditions which must have obtained during fractional precipitation from such a mixed solution. The solubilities at 18 degrees C. can be approximated from Weigel's values (given by Wells), but above this temperature there are no experimental data available for any of the sulphides. Thus, what happens to the curves at higher temperatures can only be interpreted from the relations of the minerals themselves and by assuming that the solubilities of the various sulphides in the mixed solution increase with a rise in temperature (Fig. 1). It must be emphasized that these curves are not based on experimental data but are constructed from the observed pro-

portions of the various sulphides in their various associations. The only two points that approximate known values are those just to the left of the second temperature division. The curves are not supposed to represent the curves these sulphides would show in simple solution, but are those which they show in a mixed solution of the composition of the ore-bearing solutions that deposited the Tri-State ores.

The following relations are of considerable service in determining the general form of the curves: (1) during the double precipitation of sphalerite and galena, the amount of sphalerite deposited exceeds that of galena; (2) during the triple precipitation of sphalerite, galena, and chalcopyrite, the amount of chalcopyrite deposited is greatest, that of sphalerite intermediate, and that of galena least; (3) during the quadruple precipitation of sphalerite, galena, chalcopyrite, and marcasite, the amount of marcasite is greatest, that of chalcopyrite next, that of sphalerite next, and that of galena least.

Relation (1) means that the curve of sphalerite solubility is steeper than that of galena; for over identical ranges of temperature less galena came down than sphalerite. Since this is true in the temperature ranges over which both came down together, it may be assumed that they continued to behave similarly up to the upper limit of temperatures attained.

Relation (2) means that the curve for chalcopyrite solubility is steeper than either that for galena or that for sphalerite; for over identical ranges of temperature less galena and sphalerite came down than chalcopyrite. In one exceptional case, the amount of chalcopyrite present in the specimen is many times greater than that of galena, although the amount of sphalerite present was much greater than that of chalcopyrite. In such a case the chalcopyrite might have reached its saturation temperature before galena and have been deposited first. The paragenetic studies show that this was the case, a large proportion of the chalcopyrite having come down before precipitation of galena began.

Relation (3) means that the curve for marcasite solubility is

steepest of all; for over identical ranges of temperature less galena, sphalerite, and chalcopyrite came down than marcasite.

It is on the basis of these deductions that the solubility curves given in Figure 1 were drawn. It must be remembered that the conditions in the mixed solutions were complicated by the facts that chalcopyrite is a double salt and that marcasite is a polysulphide. However, these two minerals give the sulphide ion on ionization and can therefore be considered components of a mixed solution in which the common anion was the sulphide.[15]

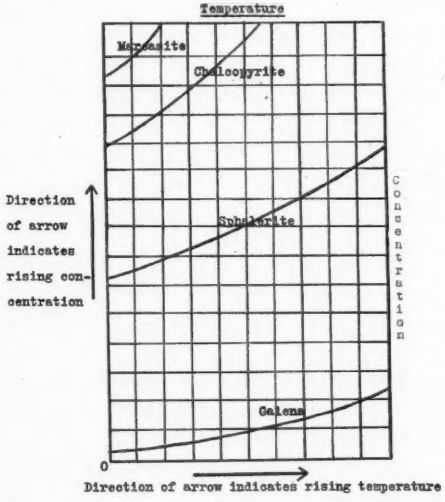


FIG. 1. Solubility curves deduced from the observed relations of the four sulphides. The curves apply only to a mixed solution of the composition of the ore-bearing solutions of the Tri-State area.

Reasons for Development of Well-Formed Crystals.—In the mixed solutions assumed, the concentrations would be very dilute and precipitation effected by gradual cooling would be a slow

[15] For a discussion of precipitation from mixed solution and the principles involved, see:

Rastall, R. H.: Physico-Chemical Geology, pp. 54–57 and 181–183, 1927.

process. Therefore, the attractive forces of crystal growth would probably have segregated the sulphides into individual crystals. This segregation explains why it is possible to determine the order of the beginning of precipitation and to estimate the quantities of the various sulphides precipitated over the same period of time.

Additional Inferences Bearing on the Character and Temperatures of the Ore-Bearing Solutions.

The ore-bearing solutions must have carried the metallic ions in balance with either (1) the sulphide ion or (2) some other ion such as the bicarbonate, or the chloride. In case (1) precipitation would be due to cooling, in case (2) to reaction with hydrogen sulphide. Thus, for each molecule of sulphide precipitated, there would have been two hydrogen ions set free from combination with sulphide ion to form carbonic or hydrochloric acid with the remaining anion. In such a process, regardless of the strength of the acid formed, the resulting solution would give an acid reaction and fluid inclusions in the sulphides would indicate that reaction. The equation is as follows:

$$Zn^{++} + 2HCO_3^- + H_2S \rightarrow ZnS\downarrow + H_2CO_3.$$

However, Newhouse found that the fluid inclusions in the Tri-State sulphides were neutral, as would be the case if the sulphides were introduced as such and precipitated by cooling.[16] Hence, it seems most probable that the cause for precipitation of the sulphides was cooling alone.

From further work on the fluid inclusions Newhouse concluded that the deposition of sphalerite and galena took place at temperatures ranging from 135°–90° C.[17] The curves given in Figure 1 are compatible with these data.

It may be concluded that the artesian hypothesis cannot ac-

[16] Newhouse, W. H.: The Composition of Vein Solutions as Shown by Liquid Inclusions in Minerals. ECON. GEOL., vol. 27, pp. 428–433, 1932.

[17] Newhouse, W. H.: The Temperature of Formation of the Minerals of the Mississippi Valley Lead-Zinc Ores. ECON. GEOL., vol. 28, p. 748, 1933.

count for the inversion in the order of the beginning of precipitation of sphalerite and galena, whereas the hydrothermal does.[18]

SUMMARY AND CONCLUSIONS.

The jasperoid is found to be composed of small xenomorphic crystals of quartz, the dark coloring being due to organic matter. The jasperoid is shown to be a replacement of the original dolomitic-limestone matrix rather than a filling of open spaces. Evidence is presented to show that the silica of the jasperoid was not deposited as a gel and that the vugs in the jasperoid were inherited from the dolomitic-limestone matrix rather than developed in the jasperoid itself.

The paragenesis of the minerals is discussed, evidence for the sequence is presented and the results summarized in a table. The most important results of the paragenetic studies are the discovery of (1) two periods of mineralization, separated by fracturing and (2) the inversion in the order of deposition of sphalerite and galena.

The observational evidence is discussed in its bearing on the leading hypotheses offered to account for the genesis of the ores. A hypothesis is offered to account for the inversion in the order of deposition. From this discussion it is concluded that the hydrothermal hypothesis can account for the observed phenomena while the artesian hypothesis cannot.

607 MELROSE STREET,
CHICAGO, ILLINOIS,
Oct. 2, 1935.

[18] The writer wishes to acknowledge his indebtedness to W. C. Pierce, Professor of Chemistry in the University of Chicago, for reading and discussing the section dealing with the inversion of the beginning of precipitation of sphalerite and galena, particularly the chemical theory involved .

DISCUSSION AND COMMUNICATIONS

CINNABAR DEPOSITS IN SOUTHWESTERN ARKANSAS [1]

Sir: Dr. N. H. Stearn's paper [2] on a part of the Arkansas quicksilver district has just been read with much interest. In a general way, Stearn's ideas on the geologic features of the district confirm those expressed by J. M. Hansell and me in our paper.[3] On only a few points of importance is there any considerable divergence. Stearn has called attention to some of these differences of opinion in his discussion [4] of our paper. I did not see Stearn's discussion before it was published and therefore will take up here points that he raises in it as well as in his recent paper in Economic Geology.

Mr. Leo Yount, at an early stage of our work in the district, kindly permitted us to view in his office at the Southwestern Quicksilver Company's plant, a copy of the excellent topographic and lithologic map formerly made by Stearn and Hansell. Although we recognized the merits of the map, we were unable to use it for Geological Survey work because, as Stearn explains,[5] it was made by pacing and altimeter methods and moreover no formational boundaries were shown on it. A portion of this outcrop map is reproduced in one of Stearn's earlier papers.[6] Our mapping was carried on by plane table stadia methods and formational and member boundaries were mapped which served as a basis for the evolution of our structural theory.

[1] Published by permission of the Director, U. S. Geological Survey.

[2] Stearn, N. H.: The Cinnabar Deposits in Southwestern Arkansas. ECON. GEOL., vol. 31, pp. 1–29, Jan.–Feb., 1936.

[3] Hansell, J. M., and Reed, J. C.: Quicksilver Deposits near Little Missouri River, Southwest Arkansas. Amer. Inst. Min. and Met. Eng. Tech. Pub. 612, 1935.

[4] Stearn, N. H.: Discussion. American Inst. Min. and Met. Eng. Trans., vol. 115, pp. 244–246, 1935.

[5] ECON. GEOL., *op. cit.*

[6] Stearn, N. H.: Mining and Furnacing Quicksilver Ore. Eng. and Min. Jour., vol. 134, fig. 1, p. 22, Jan., 1934.

In the paper just cited Stearn [7] says: "Regionally, the cinnabar zone lies on the Athens Plateau, which forms the south flank of the Ouachita Uplift, a large anticlinorium in central Arkansas. . . . The breaking of the regional anticlinorium has caused an east-west shortening, which is reflected in this area by much local faulting and cross folding." In another early paper [8] he summarizes by saying: "From a review of the detailed sedimentary features at Parnell Hill mine it can be definitely concluded that the beds are on the south flank of a regional anticline whose axial plane is nearly vertical and located somewhere north of the hill."

In our Institute paper [9] we said: "The distribution of cinnabar in a narrow belt 30 miles long suggests that the mineralizing solutions came up along the thrust fault until they encountered the fractured and faulted sandstones of the Stanley. These members, lying between thick shales to the north and south, offered channels by which the solutions could ascend toward the surface. Where these solutions had access to the cross faults cutting the Jackfork, that formation was mineralized also."

It was gratifying indeed to see in Stearn's recent paper that he coordinates his earlier ideas into a picture that essentially corresponds to ours. As he puts it: [10] "The repetition of the sedimentary series in the southern part of the Athens Plateau is effected by regional thrusting from the south, the strike of which approximately parallels that of the bedding, and the concept derived from this field work and at present accepted is that a major fault of this nature was the principal avenue of access to the mineralized solutions that deposited the cinnabar. This accounts for the linear distribution of the deposits."

This coordination of Stearn's early ideas no doubt accounts for his slight revision of Fig. 2 of his early Engineering and Mining Journal paper to Fig. 8 of his recent paper in ECONOMIC

[7] Stearn, N. H.: *op. cit.*, p. 23.

[8] Stearn, N. H.: Structure from Sedimentation, Parnell Hill Quicksilver Mine, Arkansas. ECON. GEOL., vol. 29, no. 2, p. 156, 1934.

[9] Hansell, J. M., and Reed, J. C.: *op. cit.*, p. 12.

[10] ECON. GEOL., *op. cit.*, p. 6.

GEOLOGY. The "major fault" of his early paper has been moved northward to the contact between the shale band and the sandstone hill to the north and becomes a thrust fault, and a thin sandy member stratigraphically above his Gap Ridge member is added. This agrees very well with our interpretation as shown in Figs. 2 and 8 of Technical Publication 612.

Stearn's geologic map,[11] except for one important difference, is remarkably similar to ours. He interprets the sandstone formation north of the quicksilver district as Atoka, whereas we believe it to be Jackfork. Our interpretation is based on regional mapping by H. D. Miser and A. H. Purdue,[12] on lithologic similarity, and on structural evidence. Stearn notes that our interpretation necessitates another thrust fault farther north for he says on page 7, "This massive sandstone resembles the Jackfork, but if assumed to be Jackfork it must have gotten there by thin slice faulting, which is unlikely, and of this little evidence is observable." We think that another thrust does exist to the north and we mapped a small part of it near Little Missouri River.[13] Where Stearn measured his section along Highway 27, this part of the section is not well exposed, but the sandstone band is better exposed and wider several miles farther east near Antoine Creek where at least two noses of synclinal folds may be easily traced. The presence of such folds was recognized by Miser and Purdue but their existence is not recognized by Stearn.

The eastern end of the district was mapped by the Geological Survey and the preliminary results, with a map, were published[14] after Stearn's recent paper had been sent in. On pages 12 and 13 of our paper is a suggested explanation for the cross folds and cross faults that differs somewhat from Stearn's explanation. Stearn's idea[15] appears to be that there was first compression from

[11] Stearn, N. H.: *op. cit.*, Fig. 3, p. 4.

[12] Miser, H. D., and Purdue, A. H.: Geology of the DeQueen and Caddo Gap Quadrangles. U. S. Geol. Survey Bull. 808, 1929.

[13] Hansell, J. M., and Reed, J. C.: *op. cit.*, Fig. 2, p. 7.

[14] Reed, J. C., and Hansell, J. M.: Quicksilver Deposits near Little Missouri River and near Antoine Creek, Southwestern Arkansas. U. S. Dept. of the Interior, Memorandum for the Press, April 30, 1935.

[15] Stearn, N. H.: *op. cit.*, pp. 9–11.

the south, then east-west stress, causing the east-west crustal stortening, and finally a continuation of the thrust movement from the south. In the quicksilver district the cross folds are largely localized in the overriding block just south of the southward dipping thrust fault. The writer cannot see why the effects of a regional east-west compression should be localized along that particular line and not distributed over the whole area subjected to the compression. Stearn explains this (page 11) by saying that "Especially susceptible to the east-west stresses were the Stanley and Jackfork facies which lay along the south edge of the regional thrust fault."

Our explanation, as set forth in the press memorandum, referred to above, was originally suggested by James Gilluly. It is that greater thrust movement between the eastern and western parts of the district might develop cross faults such as those found because the country lying to the east and to the west of the zone of greatest thrusting would lag behind. In the western part of the district most of the cross folds and cross faults trend northeast. In the eastern part of the district many were found to trend northwest. Thus these cross faults converge northward and movements along them resulted in east-west compression that produced the cross buckles observed. In other words, we believe the east-west shortening to be a result of unequal thrusting from the south, and not due to a temporary compression in an east-west direction between two periods of the thrusting from the south.

The writer cannot accept the extrapolation of an axis of major cross buckling[16] from the Zigzag Mountains to and beyond the east end of the quicksilver district. In fact the trend of the large Amity fault near the east end of the district is northwest and not northeast and, as pointed out, many of the smaller cross buckles and cross faults in that vicinity also trend northwest.

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[16] Stearn, N. H.: *op. cit.*, Fig. 4, p. 10.

REVIEWS

Geology and Ore Deposits of the Montezuma Quadrangle, Colorado. By T. S. Lovering. Pp. ix + 119, figs. 30, pls. 40. United States Geological Survey, Prof. Paper 178, Washington, 1935. Price $1.25.

This paper presents the results of an intensive study of the complex geology of about 230 square miles of the Colorado Front Range by a thoroughly competent man with an extensive background of experience in the surrounding territory. The results are consequently of the high order to be expected.

Very little was previously known of this area. It lies to the west of the Georgetown quadrangle and northwest of Breckinridge. The rocks are largely metamorphics and plutonic igneous intrusives of pre-Cambrian age. The southern half of the quadrangle embraces a part of the southwest end of a zone of Tertiary intrusives or the "porphyry belt" which is co-extensive with a belt of mineralization and extends southwestward from Boulder to Breckinridge athwart the structure of the pre-Cambrian. About 38 pages of the report are devoted to the petrology of the rocks, and 49 pages to the description of individual mines.

Several conclusions reached in connection with petrologic problems have more than a local significance. The oldest formation—Idaho Springs—of Algonkian ? age comprises schists and gneisses. The schistosity is nearly everywhere parallel to the bedding planes, and this is interpreted as the result of deformation at moderately high temperatures and pressures in the presence of moisture, and with the injection of countless seams of water-rich magma. The sillimanite problem is touched upon. Local facies of the schists contain discoidal lenses composed of quartz with a small amount of sillimanite. The rock resembles a metamorphosed conglomerate, but is interpreted as the product of extreme metamorphism attended by the migration of siliceous and aluminous material, in part magmatic, and in part derived from the schist itself. Sillimanite is commonly found to *replace* biotite and muscovite in the schists.

A new formation, the Swandyke hornblende gneiss, is described and interpreted as probably metamorphosed quartz diorite sills or andesitic lavas intercalated in or overlying the upper part of the Idaho Springs formation. The Idaho Springs and Swansdyke formations are invaded

by small masses of quartz monzonite and granite, which have a gneissic structure and granulation of the quartz and feldspars, and later, but during the same magmatic epoch, successively by the pre-Cambrian Pikes Peak and Silver Plume granites and related pegmatites. The generalization that the mineralogy of the pegmatites varies somewhat with a difference in the country rocks is credited to S. H. Ball and confirmed by Lovering. The gneisses and schists are strongly folded, isoclinal folds are common, and the regional structure, though modified by the nearby granitic masses, shows a north to northeast trend. The geologic map portrays most irregular borders and salient roof pendants for the Silver Plume granite. Stoping is advocated as an important factor in emplacement.

Several small patches of Cretaceous sediments are described from the southwest corner of the area.

The Tertiary intrusives are described and their sequence given. The conclusion is drawn (27) "that petrographic similarity, where not obscured by alteration, affords an important and moderately trustworthy basis for correlation." A table is given to show tentative correlation of the Tertiary intrusive rocks in the Montezuma quadrangle with those of similar age in several other districts of the Colorado porphyry belt. Magmatic differentiation is discussed. An unusual feature is an intermediate magma followed by a more mafic type in the early intrusions, and an unusual idea is the interpretation that in the differentiation of the main quartz monzonitic magma water was concentrated in the granite differentiate while the alkaline differentiate (bostonite, alkalic syenite, etc.) became relatively dry. Criteria for this are based on the occurrence of the most thorough deuteric alteration in the granites and little alteration in the alkalic rocks except along channels of mineralization; and on the occurrence of augite in the alkalic rocks as contrasted with biotites in the granites. The reviewer would note that no discussion is given to the possible hypothesis that the syenite magma was originally volatile-rich, but that pyroxene and the lack of alteration were due to conditions favoring a free escape of volatiles.

Silicification was the dominant type of alteration during the vein-forming period.

The Front Range has a north-south regional trend with *en echelon* northwesterly folds of Late Cretaceous or earliest Eocene time. These folds are commonly overturned towards the west and at many places broken by reverse faults. The largest, the Williams Range thrust fault, crosses the southwest quarter of the quadrangle and at the southeast passes into an overturned fold. A narrow belt of fractures crosses the area northeasterly from where the overturned fold passes into the thrust fault. Nearly all the Tertiary igneous activity and mineralization of the

central part of the range are localized in this belt. The veins generally occupy faults and fissures that strike from northeast to east. Horizontal movement on the easterly faults suggests shearing related to the breaking of the overturned fold where it passes into the thrust fault, and the latter is interpreted as an underthrust. It is suggested that the major porphyry stock of the quadrangle was intruded near the center of a local eastward trending anticline moving upward at an angle of about 25° to the horizontal and in a direction N. 80° E., after the period of stress when the Williams Range thrust fault was formed.

A discussion and map of the various erosion surfaces is included.

The modes of origin are listed for 103 different minerals occurring in the quadrangle. Those of economic importance include gold, silver, sulphides of lead, zinc, silver, arsenic, antimony, copper, and bismuth, and their supergene alteration products. The economically important ore deposits are mesothermal veins and stockworks. Galena, sphalerite, and pyrite are the most abundant ore minerals. Barite is abundant in a local area, and veins carrying bismuth and silver minerals with associated chalcopyrite are common in the southeast quarter of the quadrangle. In many of the ores gold and silver are associated with chalcopyrite; silver is commonly associated with tetrahedrite and tennantite; and the most abundant silver minerals, miargyrite, pyrargyrite, proustite, and stromeyerite are commonly associated with manganiferous ankerite or rhodochrosite gangue. Vertical variations in mineralization are found. Galena is commonly most abundant in the upper part of a vein, in depth copper content generally increases slightly and chalcopyrite usually becomes relatively more abundant than gray copper. In most of the lead-zinc veins sphalerite and pyrite increase with depth. Most of the silver is believed to be primary, but enrichment has affected many veins. Rich secondary gold and silver ores bottom at much shallower depths in the pre-Cambrian rocks than in the later sedimentary rocks in the western part of the quadrangle. The vertical range of ore deposition was at least 2,000 feet and probably more than 3,000 feet. Lovering concludes that the bottoms of the larger ore shoots probably indicate the bottoms of the local zones in which commercial bodies of ore were deposited nearby. The largest ore shoots range from 600 to 1,100 feet in length and have a vertical extent of 400 to 850 feet. Hard strong rocks, such as pegmatite, granite, porphyry, and gneiss, are the common walls of persistent ore shoots. Ore shoots commonly occur at the intersections of veins, near the junction of branching veins, and where marked changes in the dip or strike occur. Veins having pyritized and silicified wall rock, recording many periods of brecciation, are more likely to have been mineralized. In one case ore shoots occur where the vein breaks across the schistosity. Other suggestions for prospecting are also given.

His conclusions as to the future of the district are as follows: Reserves of high-grade ore are small, but there are many veins that might yield small but profitable amounts of ore if mined by lessees. Some of the baritic lead-zinc ores might be profitably concentrated by flotation. Moderately large bodies of low-grade auriferous disseminated zinc-lead ores, unprofitable up to the present time, occur in the stockworks near Tiger. The ore occurrences in the Ida Belle and Rainbow Mines indicate the possibility of finding ore bodies in the brecciated zone of the Williams Range thrust fault where it is crossed by mineralized fissures.

As insignificant items, the term orthogneissic (pp. vii, 12, and 13) seems to be used with unorthodox implications of a flow structure with no crushing of the minerals; 80 per cent. quartz (p. 35) in the groundmass of a sodic granite seems to call for explanation; and the statement (p. 43) that siderite or ankerite reacted with magnetite to form pyrite needs clarification.

The report is a genuine pleasure to read, for its clearness of presentation and exposition, as well as for its scientific facts and interpretations.

A. F. Buddington.

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Princeton, N. J.

Erdöl-Muttersubstanz. By F. E. Hecht and others. Pp. 181, figs. 25. Ferd. Enke, Stuttgart, 1935. Price, 17 Rm.

Because of the doubt still existing as to the origin of petroleum, it has been thought desirable to collect in one place some of the results of the studies of a few geologists who have attacked the subject from different points of view.

E. Wasmund discusses the origin of adipocere (corpse-fat) and concludes that anaerobic bacteria may make anabituminous material, not only from fatty matter, but also from albuminous substances that have been buried in mud. He illustrates his discussion with reproductions of photographs of human and other animal bodies partly altered to anabitumen (or material in the process of changing into bitumen).

K. Krejci-Graf describes various types of bituminous sediments, discusses their origin and outlines in a general way the chemistry of oil formation.

F. E. Hecht deals in more detail with the chemical processes involved in the making of petroleum, on the basis of his studies of the chemical changes undergone by the components of marine animals between the time of death and of complete fossilization and burial.

A. Treibs summarizes the evidence that plant substances (especially algal material) may change into oil, and suggests reactions which may produce this effect.

R. Potonié and D. Reunert, after recording the results of their study of the deposits in two small lakes in Prussia, conclude that the deposits of many lakes contain constituents that may under favorable conditions give rise to petroleum, but declare that many more studies on "faulschlamme" must be undertaken before it can be safely inferred that these deposits are sources of oil.

H. Steinbrecher argues that petroleum in nature may very probably have been produced at low temperatures.

The final paper of the collection, by Dora Wolansky, is mainly a summary of the results reached by Russian geologists in the study of the sediments of the Black Sea, and their conclusions as to the method of origin of oil. Their general feeling is that, whatever may have been the source material of petroleum, its production was due largely to biochemical processes.

W. S. BAYLEY.

Hot Spring of the Yellowstone National Park, by E. T. ALLEN AND ARTHUR L. DAY, with microscopic examinations by H. E. MERWIN. Quarto; pp. 525; figs. 215. Carnegie Foundation of Washington, 1936 (Feb.).[1]

This elaborate study of a noteworthy region is fittingly presented in a monograph that is beautifully printed, and magnificently illustrated.

The extent of the report may be illustrated by listing the major subjects covered. It opens with an interesting history of the park followed by a general description. The relation between rainfall and spring discharge is discussed. Numerous chemical analyses of spring waters and volcanic gases are given and discussed in detail. The rock decomposition effected by alkaline, acid, and mixed waters is described; and also the materials they have deposited. Geysers and theories of geyser action are taken up in detail. The various geysers and groups of geysers are described together with their relation to water supply and heat supply. Areas of acid deposits, travertine deposits and mixed deposits are described. Many interesting subjects included under these major ones cannot even be listed since the table of contents alone covers over seven pages.

A very few of the observations and conclusions that will most interest geologists may be cited. Many springs show the extraordinary thermal feature of water above its boiling point, and this superheat may vary from a fraction of a degree to 3° C. or more in rare instances. Then follow data on a large number of springs that show this feature. The temperatures of a number of steam vents are given, and these vary up to a maximum of 138.3° C. The authors conclude that the steam must have

[1] Printed by permission of the Director of the United States Geological Survey.

come from considerable depth and point out that the pressures increase with depth. Steam superheated at the surface must have remained superheated throughout its passage from the magma. Superheated steam could not have been derived from any underground water reservoir or from water descending from the surface since such steam would be saturated. They conclude that in the Yellowstone Park, as at Katmai, the hot springs are the result of circulating groundwater of surface origin, augmented and heated by steam originally in a superheated state, rising from an underlying magma. The superheated steam of the vents is believed to be partly, but not wholly magmatic. As swift rushing steam makes its way through ground, relatively dry, it evaporates a variable amount of ground water and its temperature is reduced proportionally, but steam and ground water reach equilibrium only in saturated jets.

The writers give measurements of the approximate discharge of the various thermal springs of the region and find a total of 109.12 cubic feet per second.

Water in the dominant component of the vents. The composition of a typical one is as follows:

H_2O	99.600
CO_2	.386
H_2S	.010
H_2	.002
CH_4	negligible
$N_2 + A$	.002
	100.000

The average percentage composition of the permanent gases of the region, corrected for the air content is CO_2 98.26, H_2 0.11, CH_4 0.11, $N+A$ 0.86, H_2S 0.66. The CO_2 content is low in gases escaping from alkaline areas and it is believed that this is due to its absorption below ground in the formation of bicarbonates.

One of the few conclusions with which many geologists may not fully agree occurs in the last clause of the following paragraph (p. 94):

"That the valuable metals in ore deposits may have been transported in the gaseous state is now accepted by many geologists, and while conclusions on the generality of a process, in which all the evidence is indirect, may be indefinitely delayed, the principle of critical temperature is of doubtful application to the problems; and the conception of a continuous gaseous exhalation from a hot body containing volatile matter is not only the simplest, but is in agreement with all our knowledge of hot springs; while the alternate view—the transportation of any aqueous solution from the magma to the surface—has so far proved impossible to harmonize with the facts."

In areas of Yellowstone Park where acid waters have produced rock alteration the rhyolites, either massive or in the form of gravels, may be found in various states of decomposition down to practically pure silica. The material commonly shows a dull bleached groundmass, generally pitted with angular cavities from which the feldspars and part of the quartz grains have been removed. A study of rock decomposition in alkaline areas shows several interesting things. In an area where carbon dioxide was abundant, but where sinter was not being deposited, the fine-grained groundmass whether glassy or felsic, and to a much smaller extent of feldspar phenocrysts, along their cleavage cracks are passing into clay (beidellite). Chemical analyses show a loss of alkali, especially sodium. A widespread alteration to clay is undoubtedly going on at the surface, but is evidently limited in depth. A test hole was drilled in the Upper Basin in 1929, and here no clay was found below the sinter deposit Microscopic examination by Fenner showed that feldspar phenocrysts were little attacked. A chemical analysis showed a notably higher potash content in the altered rhyolite than in the original material. Sodium is dominant in the escaping solutions, but in this altered rhyolite there has been a base exchange by which sodium feldspar has been almost completely altered to potash feldspar. This introduced potassium is believed to have been originally present in the escaping solutions as potassium chloride which was largely removed before reaching the surface.

The dissolved matter escaping in the thermal waters of the Park is estimated to be about 352,000 kilos or 390 tons per day and the 102.9 cubic feet of water that escapes each second carries with it 207,000 kilogram calories of heat, or enough to melt 3 tons of ice every second.

Geysers and the cause of geyser action are discussed, and the authors conclude (pp. 514) that a number of new facts presented by the 200 geysers of the Park indicate the existence of an underground chamber for the generation of steam connected with the geyser tube or well by a narrow conduit more or less horizontal. The intermittent rise and fall of the water level, characteristic of a large number of geysers, is strongly suggestive of the alternate expansion and condension of steam—changes which might readily take place in an underground chamber invisible from the surface, but would obviously be impossible in a vertical tube open to the sky. Still more compelling is the fact that the discharge of certain powerful geysers far exceeds the capacity of their wells. Separate supplies of heat for both reservoir and geyser well, would explain why geysers which have become dormant or dead may still be boiling, or even superheated at the mouth of the well.

Part II of the report (233–515) is devoted to descriptions of the different springs, geysers, mud pots, terraces and related features of Yellowstone National Park.

A valuable feature of the study has been the effort to make all data quantitative wherever possible. The detail and completeness of the study, the thoroughness of all the work, and the care with which previous work and theories have been presented make this report one that will be a standard work of reference for all those interested in problems of volcanism.

CLARENCE S. ROSS.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.

Introduction to Petrofabric Analysis. By H. W. FAIRBAIRN. Mimeographed notes published by the Department of Geology, Queen's University, Kingston, Ontario, 1935. Text, 141 pp.; figures, 10 pp. Price, $1.00 postpaid.

In the introduction, the purpose and concepts of petrofabric analysis are outlined. The next section describes its methods in some detail. Then follows a résumé of the work already done in the field; its description and interpretation. An attempt is made throughout to organize the material so that its relation to American ideas may be grasped. Foliated rocks receive considerable attention in this respect. The appendices contain an alphabetical register of German terms in common use, the main literature on the subject, and an index.

BOOKS RECEIVED.

L. B. RILEY.

Pre-Cambrian Rocks of the Lake Superior Region, with Revised Geologic Map. C. K. LEITH, R. J. LUND, AND A. LEITH. Pp. 34. U. S. Geol. Surv. Prof. Paper 184. Washington, 1935. 60 cts. A review of geologic features discovered since the publication of Monograph 52 (1911). "Archean" and "Algonkian" are defined as rock types instead of time units. Correlations have been revised. Recent theories of the genesis of the iron ores are briefly reviewed.

A Brief Review of the Geology of the San Juan Region of Southwestern Colorado. W. CROSS AND E. S. LARSEN. Pp. 138, pls. 16, figs. 2. U. S. Geol. Survey Bull. 843. Washington, 1935. $1.00. The geology of one eighth of Colorado is condensed into this paper with the aid of the accompanying geologic map. The contributions on pre-Cambrian and Tertiary igneous geology are noteworthy. Only a general treatment is given the economic geology, as the important mining districts have previously been described in detail.

Geology of the Tonsina District, Alaska. F. H. MOFFIT. Pp. 38, fig. 4, map. U. S. Geol. Surv. Bull. 866. Washington, 1935. 40 cts. The geology of an area of about 3000 sq. mi. in the Copper River Basin. Tertiary granitic intrusives have invaded Carboniferous and Mesozoic sediments. Rich, although small, gold veins are a part of the accompanying mineralization.

Mineral Yearbook, 1935. O. E. KIESSLING, compiler. Pp. 1293. U. S. Bur. Mines. Washington, 1935. $2.00. The valuable compilation of statistics formerly published as "Mineral Resources." A chapter on world production and international mineral policies is of general interest.

The Early Iron Industry of Connecticut. H. C. KEITH AND C. R. HARTE. Pp. 69. Reprinted from the 51st Ann. Rept., Conn. Soc. Civil Engineers, Inc. New Haven, 1935. A brief history of the mining and smelting of iron in the state, 1658 to 1920.

A Preliminary Investigation of the Bleaching Clays of Mississippi. H. X. BAY. Pp. 62, figs. 4. Miss. State Geol. Surv. Bull. 29. University, Miss., 1935. Both naturally active and activable types of bleaching clay are regarded as derived from volcanic ash. Beds are found in the Ordovician, Upper Cretaceous, and early Tertiary.

Limestones of Canada, Part III (Quebec). M. F. GOUDGE. Pp. 275, pls. 36, figs. 13. Canada Dept. Mines, Mines Branch, Report 755. Ottawa, 1935. 50 cts. The occurrence and chemical and physical properties of the limestone in the province.

Laboratory Tests on Structural Assemblies of Brick and Tile. L. P. COLLIN. Pp. 33. Canada Dept. Mines, Mines Branch, Report 766. Ottawa, 1935. 10 cts.

Mining Handbook of Australia, 1936. Editorial Staff, Chem. Eng. and Mining Review. Tait Publishing Co., Melbourne, 1935. Pp. 480. 20/—. A condensed directory of 800 mining companies operating in Australia, New Guinea, Papua, Fiji, Malaya, and New Zealand; 80 pages are devoted to production statistics (1910–1934); mining laws of Australia, Fiji, and New Guinea; a glossary of technical terms; and tables and method for evaluation of mining shares.

Contribuicao para a Geologia do Estado de Goyaz, Brazil. G. B. MILWARD. Pp. 98, map. Escolas Profissionaes Salesianas, Sao Paulo, 1935. The geology of part of western Minas Geraes and eastern Goyaz, Brazil.

Le Batholite de Mokambo (Katanga) et ses alentours. M. LECOMPTE. Pp. 128–225, pls. X–XVIII. Mem. Inst. Geol. Univ. Louvain, Tome VII, Fasc. III. Louvain, 1933. A study of the Mokambo granite batholith and the surrounding sedimentaries of the Katanga Series.

Studies of Relations of Rainfall and Run-off in the United States. W. G. HOYT AND OTHERS. Pp. 301, figs. 89, tbls. 66. U. S. Geol. Surv. Water-supply Paper 772. Washington, 1936. 25 cts. Work done by U. S. Geol. Survey under direction of the Water Planning Committee, National Resources Board. Contains a wealth of information on the hydrology of the United States through a quantitative study of the various divisions of the hydrologic cycle (precipitation, groundwater and surface run-off, and, by difference, transpiration and evaporation).

Floods in the United States, Magnitude and Frequency. C. S. JARVIS. AND OTHERS. Pp. 497, pls. 2, figs. 22. U. S. Geol. Surv. Water-supply Paper 771. Washington, 1936. $1.00. Work done by U. S. Geol. Survey under direction of Water Planning Committee, National Resources Board. Methods for analyzing flood flow data and for estimating expected floods; records of floods on many rivers. A glossary of terms and an extensive bibliography is appended.

Zinc and Lead Deposits of Northern Arkansas. E. T. MCKNIGHT. Pp. 311, pls. 11, figs. 19. U. S. Geol. Surv. Bull. 853. Washington, 1935. $1.00. A complete account of the geology of northern Arkansas. The ore deposits, although of slight economic importance, are of especial interest in relation to the Tristate-Mississippi Valley type of deposit. The conclusion is drawn that the ore deposits are at least in part of igneous origin. The recognition of enargite is interesting.

Geology of the Santa Rita Mining Area, New Mexico. A. C. SPENCER AND SIDNEY PAIGE. Pp. 78, pls. 6, fig. 1. U. S. Geol. Surv. Bull. 859. Washington, 1935. 40 cts. The area includes the most productive part of the Hanover (or Central) mining district. The principal ore deposits include large contact-metamorphic deposits; the sphalerite deposits in the vicinity of Hanover and Fierro; and the great deposit of disseminated copper sulphide at Santa Rita.

Geologic Map of Colorado, by the U. S. Geological Survey, Colorado Geological Survey, and Colorado Metal Mining Fund. Scale 1/500,000; 2 sheets each 34 x 46; legend compiled by W. S. Burbank, T. S. Lovering, E. N. Goddard and E. B. Eckel. Edited by G. W. Stose. U. S. Geological Survey, Washington, 1935 (1936). Price $2.00. Excellent map, carefully colored; includes list of sources of data.

Chibougamau Lake Map-area, Quebec. J. B. MAWDSLEY AND G. W. H. NORMAN. Pp. 95, pls. 5, fig. 1, map. Can. Geol. Surv. Mem. 185. Ottawa, 1935. 25 cts. Gold-bearing copper sulphides and gold-quartz deposits in a pre-Cambrian complex. Two deposits are in an advanced stage of exploration.

SOCIETY OF ECONOMIC GEOLOGISTS

Field Trip.—The Society of Economic Geologists will hold a three day field meeting in the Northwest Adirondacks on October 2d, 3d, and 4th, 1936. Headquarters will be the St. Lawrence Inn at Gouverneur. This is about 107 miles from Syracuse, N. Y.; 316 miles from New York City; 357 miles from Boston, Massachusetts; and 97 miles from Ottawa, Ontario. The tentative program calls for visits to post-Cambrian lead-zinc fissure vein deposits, hematite deposits at the base of the Potsdam sandstone, pyrite deposits in Precambrian gneiss, magnetite replacements of gneiss at Benson mines, talc mill and talc deposits, the Edwards and Balmat pyritic sphalerite deposits in the Grenville limestone and the mine and mill at Balmat. The Balmat deposit shows at relatively deep levels oxidized mineralization and light colored sphalerite and willemite whose origin has been attributed to the activities of surface waters. Papers on this subject by Dr. J. S. Brown will appear shortly in ECONOMIC GEOLOGY, and opportunity will be afforded to study these phenomena underground with his leadership. The time for presentation of papers will be limited to the evenings. A program dealing with the geology and ore deposits of the region is being arranged, and contributions from members should be restricted to subjects related to such topics. The title and abstracts of papers to be submitted should be in the hands of A. F. Buddington, Princeton, N. J., before September 1st. The committee on arrangements is J. S. Brown, A. F. Buddington, D. H. Newland, and Edward Sampson.

Annotated Bibliography.—Sponsorship for the publication of the Annotated Bibliography of Economic Geology has been transferred from the Division of Geology and Geography of the National Research Council to the Society of Economic Geologists. Financial support is assured for the year starting July 1, 1936, and efforts are being made to secure funds adequate for subsequent publication on a permanent basis.

SCIENTIFIC NOTES AND NEWS

Waldemar Lindgren has been awarded the Gustave Trasenster Medal for 1936 by the Association des Ingenieurs sortis de l'Ecole de Liége.

E. L. DeGolyer has bought a house in Brookside Estates, Dallas, Texas, where he will henceforth make his home.

A. C. Lawson is spending several months abroad. He will visit Spain, Morocco, France, Germany, and England before returning to the United States in August.

C. W. Wright, Foreign Mineral Specialist of the U. S. Bureau of Mines, who is aiding the American Consular Service in making special reports and surveys of the mineral industries in Europe, has recently changed headquarters from Rome, Italy, to Berlin, Germany.

J. B. Tyrrell has changed his address from The Canadian Bank of Commerce Building, 25 King Street West, to Room 1314 Metropolitan Building, 44 Victoria Street, Toronto, Ontario, Canada.

N. H. Darton, who has recently completed 50 years of service in the United States Geological Survey, has been retained in the service after having passed the retirement age, by the order of President Roosevelt.

W. C. Mendenhall, Director of the U. S. Geological Survey, has been elected president of the Geological Society of America for 1936, W. E. Wrather and George D. Louderback, vice-presidents.

H. S. Munroe has been appointed consulting engineer for Ventures, Limited. He is also a director of the company.

Erle V. Daveler, treasurer of the Utah Copper Co., has been elected president of the Mining and Metallurgical Society of America.

W. Val de Camp is doing consulting work for Maurecio Hochschild in Bolivia at the Huanchaca property, Pulacayo, Potosi.

P. D. Wilson, vice-president of Pardners Mines Corp., New York, has gone to Siam to visit the Pinyok tin mine in which his company is interested.

R. V. Johnson, consulting geologist in Alberta and British Columbia, with headquarters in Calgary, has been elected president of the Alberta Society of Petroleum Geologists for the current year.

V. E. Oppenheim, consulting geologist to the Serviço de Fomento da Producçao Mineral, of Brazil, has returned to Rio de Janeiro after a five months' reconnaissance survey of the upper part of the Territory of Acre and the bordering areas of Peru and Bolivia.

G. G. Dobbs, formerly of the Gold Coast Selection Trust, is now general manager of the Ariston Gold Mines, Limited, at Prestea, Gold Coast Colony, West Africa.

R. J. Colony, associate professor of geology at Columbia University, died on March 26, at the age of 66 years.

The graduate class in geology at Queen's University has had a series of lectures in which Mr. E. Y. Dougherty has presented a discussion of the geology of the Vipond mine, Mr. W. C. Ringsleben, one of the Hollinger mine, and Mr. H. C. Rickaby, Provincial Geologist of Ontario, two lectures on the geology and ore deposits of the Sudbury district.

The Geological Society of London in 1935 made the following grants from the J. B. Tyrrell Fund: (1) £150 to W. H. Wilcockson for a study of the Rossland Complex and the Metalliferous deposits of British Columbia; (2) £50 to T. C. Phemister for a study of the Coast Range batholith north of Vancouver.

The Association of American State Geologists elected as officers, G. C. Branner, State Geologist of Arkansas, President; Arthur Bevan, State Geologist of Virginia, Secretary; and R. C. Moore, State Geologist of Kansas, Third Member of the Executive Committee.

The Canadian Institute of Mining and Metallurgy held its annual meeting at Ottawa, March 17–19. The attendance was representative; the sessions interesting, and the social functions enjoyable. Among the papers of interest particularly to geologists were: Lake Shore Geology, by W. T. Robson; Lake Shore Mining Methods and Practices, by L. S. Weldon; Lake Shore Milling, by B. S. Crocker and C. L. Williamson; Mine Dust, by T. L. Walker; Salt, by R. M. Rowat; Gold Deposits of Lake Athabasca, by F. J. Alcock; Gold Deposits, Ontario, by J. E. Thomson; Eastern Porcupine Area, by M. E. Hurst; Chibougamau-Waswanipi, by G. W. H. Norman; Geology in Prospecting Western Quebec, by L. V. Bell; Gold Deposits, Afton and Scholes Townships, by E. S. Moore; Bauxite Mining, British Guiana, by E. C. Harder; Industrial Minerals in Metallurgy, by W. E. Newton, T. V. Lord, T. H. Weldon, and R. D. Perry; and a group of mining reviews for 1935 of each of the Provinces.

The Section of Geology and Geography of the American Association for the Advancement of Science will hold a summer meeting in Rochester, New York, June 17 and 18. Papers dealing with New York State geology will be presented and the one hundredth anniversary of the New York State Geological Survey will be celebrated. Titles should be submitted to Dr. E. F. Hoffmeister, University of Chicago, by May 9th.

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